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# **CHAPTER 6**

## **GEOTECHNICAL**

### **6.1 GENERAL**

This Chapter provides guidance for all geotechnical investigations, analyses and reports produced by the Federal Lands Highway Divisions. Although greatly advanced in recent years, the state-of-the-art of the geotechnical engineering field is still largely dependent upon engineering judgment to provide the most efficient and economical investigations. Dealing with the variability of projects, terrains, climates and client agency constraints requires flexibility and resourcefulness.

Although primarily intended for use by a geotechnical engineer/geologist, the information contained herein can be used by designers and others during the design process. Geotechnical responsibilities include conducting investigations, performing analyses and providing recommendations for the following:

- geological and geotechnical reconnaissance,
- cut and fill slopes,
- foundations,
- landslides,
- material sources,
- retaining walls,
- subsurface drainage, and
- pavements.

Each of these areas are addressed individually, providing guidelines, direction and references for more specific and detailed information.

## 6.2 GUIDANCE AND REFERENCES

The publications listed in this Section provided much of the fundamental source information used in the development of this Chapter. While this list is not all-inclusive, the publications listed will provide additional information to supplement this *Manual*.

### 6.2.1 GENERAL REFERENCES

1. Bowles, *Foundation Analysis and Design*, 4<sup>th</sup> edition, McGraw-Hill Book Company, 1988.
2. Peck, Hanson, and Thornburn, *Foundation Engineering*, John Wiley and Sons, Inc., 1974.
3. Terzaghi and Peck, *Soil Mechanics in Engineering Practice*, John Wiley and Sons, Inc., 1967.
4. Wintercorn, *Foundation Engineering Handbook*, 2<sup>nd</sup> edition, Van Nostrand Reinhold Company, 1991.
5. *Canadian Foundation Engineering Manual*, 3<sup>rd</sup> edition, Canadian Geotechnical Society, 1992.
6. [\*Geotechnical Engineering Notebook\*](#), DOT, FHWA, Office of Engineering, Bridge Division.
7. [\*Geotextile Engineering Manual\*](#), DOT, FHWA, 1984.
8. Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction, *NAVFAC Design Manual 7.3*, Department of the Navy, April 1983.
9. Soil Mechanics, *NAVFAC Design Manual 7.1*, Department of the Navy, September 1986.

### 6.2.2 GEOLOGY, LANDSLIDES AND FIELD PROCEDURES

1. Acker, *Basic Procedures for Soil Sampling and Core Drilling*, Acker Drill Co., Inc., 1974.
2. Beck, *Physical Principles of Exploration Methods*, New York, John Wiley and Sons, Inc., 1982.
3. Deere, D. U., *Geological Considerations, Rock Mechanics in Engineering Practice*, edition R. G. Stagg and D. C. Zienkiewicz, Wiley, New York, 1968.
4. Hamblin and Howard, *Physical Geology Laboratory Manual*, Minneapolis, Burgess Publishing Co., 1975.
5. Hunt, *Geotechnical Engineering Investigation Manual*, New York, McGraw-Hill Book Co., 1984.

6. Pitts, *A Manual of Geology for Civil Engineers*, Salt Lake City, John Wiley and Sons, Inc., 1984.
7. *Manual on Subsurface Investigations*, AASHTO, 1988.
8. *Driller's Safety Manual*, US Department of the Interior, Bureau of Reclamation, 1973.
9. Geotechnical Instrumentation, *FHWA Workshop Manual*, DOT, FHWA.
10. *The Cone Penetrometer Test*, FHWA-SA-91-043, DOT, FHWA, 1992.
11. *The Flat Dilatometer Test*, FHWA-SA-91-044M, DOT, FHWA, 1992.
12. *Advanced Technology for Soil Slope Stability*, FHWA-SA-94-005, DOT, FHWA, 1994.
13. *Handbook of Engineering Geophysics* (Volume 1, Seismic, 1984 and Volume 2, Electrical Resistivity, 1980), Minneapolis, Bison Instruments, Inc.
14. *The Pressuremeter Test for Highway Application*, FHWA-IP-89-008, DOT, FHWA, 1989.
15. *Landslides Investigation and Mitigation*, Transportation Research Board, National Academy of Sciences, Washington, DC, 1995.
16. [\*Rock Slopes: Design, Excavation, Stabilization\*](#), FHWA-TS-89-045, DOT, FHWA, 1989.
17. [\*Rock Blasting and Overbreak Control\*](#), FHWA-HI-92-001, DOT, FHWA, 1991.
18. Duncliff, *Geotechnical Instrumentation for Monitoring Field Performance*, John Wiley & Sons, Inc., 1988.

### 6.2.3 STRUCTURES AND FOUNDATIONS

1. Poulos and Davis, *Pile Foundation Analysis and Design*, 1980.
2. [\*Drilled Shafts: Construction Procedures and Design Methods\*](#), DOT, FHWA, 1988.
3. [\*Handbook on Design of Piles and Drilled Shafts Under Lateral Load\*](#), FHWA-IP-84-011, DOT, FHWA, 1984.
4. [\*Behavior of Piles and Pile Groups Under Lateral Load\*](#), FHWA-RD-85-106, DOT, FHWA, 1986.
5. *LFRD Bridge Design Specifications*, AASHTO, 1994.
6. Reeves, *Applications of Walls to Landslide Control Problems*, American Society of Civil Engineers, 1982.
7. [\*Spread Footings for Highway Bridges\*](#), FHWA-RD-86-185, DOT, FHWA, 1987.
8. *Manual on Foundation Investigation*, AASHTO, 1978.

9. AASHTO-AGC-ARTBA Taskforce Report, *In-Situ Improvement Techniques*, 1990.
10. Foundation and Earth Structures, *NAVFAC Design Manual 7.2*; NAVFAC DM-7.2, Department of the Navy, 1982.
11. *Permanent Ground Anchors*, FHWA-DP-68-1R, DOT, FHWA, 1984.
12. [\*Manual on Design and Construction of Driven Pile Foundations\*](#), FHWA DP-66-1, DOT, FHWA, Office of Engineering, Bridge Division, 1986.
13. [\*Retaining Wall Design Guide\*](#), 2<sup>nd</sup> edition (FHWA-FLP-94-006), US Department of Agriculture, Forest Service, September 1994.
14. [\*Soils and Foundation Workshop Manual\*](#), DOT, FHWA, Office of Engineering, Bridge Division, 1993.

#### 6.2.4 MATERIAL AND PAVEMENT DESIGN

1. *Techniques for Pavement Rehabilitation, A Training Course*, 3<sup>rd</sup> Revision, ERES Consultants, Inc., 1987.
2. *Pavement Design Principles and Practices, A Training Course*, ERES Consultants, Inc., 1987.
3. Krebs and Walker, *Highway Materials*, McGraw-Hill Book Company, 1971.
4. Yoder and Witczak, *Principles of Pavement Design*, 2<sup>nd</sup> edition, John Wiley and Sons, Inc., 1975.
5. [\*AASHTO Pavement Overlay Design\*](#), FHWA-HI-94-048, DOT, FHWA, 1994.
6. *Distress Identification Manual for the Long-Term Pavement Performance Projects*, SHRP-P-338, SHRP, 1993.
7. *Guide for Design of Pavement Structures*, AASHTO, 1993.
8. [\*Pavement Rehabilitation Manual\*](#), DOT, FHWA, Office of Engineering, Pavement Division, 1990.
9. *Soils Manual for the Design of Asphalt Pavement Structures*, The Asphalt Institute, 1986.
10. *Thickness Design - Asphalt Pavements for Highways and Streets*, The Asphalt Institute, 1991.
11. [\*Pavement Notebook for FHWA Engineers\*](#), FHWA, Office of Engineering, Pavement Division.



### 6.2.5 SUBSURFACE DRAINAGE

1. [\*Geotextile Design and Construction Guidelines\*](#), FHWA-HI-95-038, DOT, FHWA, 1995.
2. Drainage of Asphalt Pavement Structures, *The Asphalt Institute Manual*, Series No. 15, September 1984 edition
3. [\*Geocomposite Drains\*](#), Report No. FHWA/RD-86/171, DOT, FHWA, October 1986.
4. [\*Geotechnical Fabrics\*](#), Report No. FHWA/RD-80/021, DOT, FHWA, 1980.
5. [\*Highway Subdrainage Design\*](#), Report No. FHWA-TS-80-224, DOT, FHWA, 1980.
6. [\*Improving Subdrainage and Shoulders of Existing Pavements\*](#), Report No. FHWA/RD-81/078, DOT, FHWA, January 1982.
7. [\*Underground Disposal of Storm Water Runoff\*](#), Report No. FHWA-TS-80-218, DOT, FHWA, March 1980.

### 6.2.6 COMPUTER PROGRAMS

The following is a listing of computer programs that are available and may be used when appropriate:

1. **Foundations.** The following computer programs are used for analyzing soils for foundations:
  - GRL WEAP - Wave Equation Analysis of Piles,
  - NAVPILE - Nevada Pile Analysis (Static),
  - COM 624 P - Lateral Load Analysis of Driven and Non-Driven Piles,
  - DRIVEN - Ultimate Static Capacity for Driven Piles,
  - CBEAR - Bearing Capacity Analysis for Shallow Foundations,
  - FOSSA – Settlement Analysis, and
  - SIGMA/W – Settlement Analysis.
2. **Pavement Design.** The following applies to pavement design:
  - DARWIN - Pavement Design Analysis and Rehabilitation for Windows, and
  - DAMA - Pavement Structural Analysis Using Multi-Layer Elastic Theory.
3. **Slope Stability.** Computer programs that investigate slope stability include the following:
  - XSTABL - Slope Stability Analysis,
  - SLOPE/W – Slope Stability Analysis,
  - DIGIPRO - Data Reduction and Graphing Software for Inclinometers,
  - EMBANK - One Dimensional Consolidation due to Embankment Loads,
  - SEEP/W – Finite Element Groundwater Analysis, and
  - RESSA – Reinforced Earth Slope Stability Analysis.

4. **Geophysical Programs.** The following computer programs analyze geophysical survey data:
- SEISMIC12 - Channel Refraction Seismic Test Data Analysis,
  - RESIST - Resistivity Data Analysis, and
  - SEISREFA - Seismic Refraction Analysis.
5. **Retaining Structures.** The following computer programs analyze stability:
- MSEW – Mechanically Stabilized Earth Wall Design, and
  - RESSA – Reinforced Earth Slope Design.

## 6.3 INVESTIGATION PROCESS

The primary purpose of a geotechnical investigation is to provide design engineers with a knowledge of the subsurface conditions at a specific project site. The investigation should also provide the construction project engineers and contractors with information concerning the materials and conditions that may be encountered in the field.

The scope and cost of a geotechnical investigation should be adjusted to the size and complexity of the proposed project. The potential for catastrophic failure and/or failure consequences must be evaluated when establishing the scope of the investigation.

In all geotechnical investigations, the safety of the field crew and the traveling public must be of high priority. The nature of the equipment used and climatic conditions often present potential hazards that must be evaluated on an individual basis. It is the responsibility of the geotechnical engineer/geologist, as well as field crew members to adjust the investigation program and/or provide equipment, training and other means to provide safe working conditions. Field crews should be aware of and use traffic safety control plans based upon [MUTCD](#) requirements.

Geotechnical investigations should not be attempted until certain project-specific information has been obtained. Refer to [Chapter 4](#) for the type of information that is obtained for conceptual studies and preliminary design. [Exhibit 6.3-A](#) identifies typical project requirements and suggests where the necessary information on specific subjects may be obtained. [Exhibit 6.3-B](#) provides a form that is used to gather and document this preliminary information.

Special situations occasionally require in-situ testing or instrumentation to obtain accurate information for both design and construction. These tests and instrumentation may be highly specialized and may require specialized assistance. The following are typical reasons for specialized instrumentation:

- construction control (i.e., both during design and/or construction);
- safety;
- verifying design assumptions;
- verifying new construction techniques;
- verifying long-term satisfactory performance; and
- determination of slope stability.

### 6.3.1 GEOTECHNICAL EQUIPMENT

Sometimes to perform geotechnical investigations, specialized subsurface investigation equipment is required. In cases of sporadic use or when highly trained technicians must be assigned exclusively to operate equipment, the Geotechnical Unit may prefer to use consultants and/or contractors to provide these services in lieu of actually purchasing and maintaining this type of equipment. Below are typical sources for technical assistance to obtain equipment or expertise:

- other FLH offices,
- FHWA research and implementation units,

- local and State government agencies,
- other Federal government agencies,
- universities,
- private consultants, and
- equipment manufacturers.

Each Geotechnical Unit should maintain access to the latest equipment and technology so it can perform efficient and effective investigations. This policy also provides FHWA the opportunity to implement and experiment with new technology, equipment and ideas. Equipment can be grouped into three major categories:

- drill equipment and sampling tools,
- geophysical and in-situ testing equipment, and
- pavement evaluation equipment.

In addition to these major areas, incidental hand tools are required for the generalized reconnaissance type of investigations usually performed by an engineer or geologist. This equipment consists of, at a minimum:

- a Brunton compass,
- survey transit,
- cloth tape,
- hand level,
- rock hammer,
- hand augers,
- test pit excavation equipment, and
- record keeping notebooks.

Minimum drill equipment should consist of a power auger drill rig capable of advancing an 200-mm (8-in) hollow stem auger to 35 m (115 ft) in very stiff clays or dense sand and gravel. The drill should be capable of traversing soft ground, moderately steep slopes and rough terrain. The drill should also have capabilities for obtaining at least 45 m (148 ft) of “N” size or larger rock cores. Environmentally sensitive work areas are increasingly demanding low-impact exploration methods with portable drills lifted into place with boom trucks or by helicopter. Soil testing and sampling capabilities should consist of at least the Standard Penetration Test AASHTO T 206-87(2000) and the Thin Walled Tube Sample AASHTO T 207-96(2000). In addition to the large drilling equipment, a portable drill capable of drilling at least “B” size cores a minimum of 15 m (50 ft) is desirable. Hunt’s *Geotechnical Engineering Investigation Manual* provides an excellent source of detailed information on investigation equipment requirements.

Minimum in-situ test equipment should include a cone penetrometer, a vane shear and in-place density equipment (e.g., sand cone, nuclear gauge). Project site instrumentation (e.g., inclinometer, piezometer, strain gage readout devices) should also be available. A detailed instrumentation equipment listing is available in the *Geotechnical Instrumentation for Monitoring Field Performance* by Dunncliff.

Available pavement evaluation equipment should consist of a calibrated distance measuring device, pavement deflection equipment, roughness measurement and pavement core drill. In addition, access and familiarity with skid testing devices, photo logging and videotape equipment is desirable.

[Exhibit 6.3-C](#) provides guidelines for the type of equipment and the frequency of use that is typical for different types of geotechnical investigations.

### 6.3.2 PLANNING GEOTECHNICAL INVESTIGATIONS

After the project has been initiated, the first phase of any geotechnical investigation should consist of a desk review of available geotechnical information and project specific requirements and information. Refer to [Chapter 4](#) for the overall process for project scoping and information collected for conceptual studies and preliminary design. This information is vital to planning an efficient, cost-effective field investigation. The information is used to do the following:

- determine the nature and scope of the geotechnical field investigation;
- select proper field equipment;
- estimate staffing needs, time and total costs;
- assess environmental clearances that may be required
- select field reference system for geotechnical reports; and
- determine site conditions that may restrict or limit the investigation.

The wide range of geographical areas where projects may be located requires access to geotechnical information from a variety of sources. [Exhibit 6.3-D](#) provides an initial listing of potential sources and a brief description of information available. Each geotechnical unit should supplement the sources listed in [Exhibit 6.3-D](#) by establishing and maintaining a file of commonly used regional information.

In addition, the following should be available from the local and/or in-house resource center:

- aerial photographs,
- geologic maps,
- previous geotechnical reports,
- survey notes, and
- as-built plans.

After this information is obtained and studied, a preliminary boring plan should be developed. This boring plan should contain information on the following:

- type, number and location of proposed test holes;
- estimated depth, type of testing and sampling interval for each hole;
- exploration site access and environmental clearances required;
- instrumentation plans;
- type and location of utilities;
- list of local contacts for right-of-access and for utilities;
- arrangements for traffic control (e.g., flaggers, signing);

- source of drilling water; and
- instructions for communications, sample handling.

[Exhibits 6.3-E](#) and [6.3-F](#) may be used as guidelines for development of an investigation plan. An on-site visit is desirable and often required as part of the development of a detailed investigation plan before field crews begin work at the project site.

### 6.3.3 DRILLING AND SAMPLING

The purpose of a drilling and sampling program is to obtain samples that reasonably represent subsurface conditions over the entire project site. Guidance for selection of the applicable boring test type can be found in [Exhibit 6.3-G](#).

Sampling type and frequency is dependent upon both the type of material encountered and the purpose of the investigation. The *AASHTO Manual on Subsurface Investigation* provides additional detailed information. When appropriate, continuous sampling provides the most complete and accurate information. When equipment, materials or cost effectiveness prevent continuous sampling, the typical sampling frequencies used are provided in [Exhibit 6.3-H](#). The preliminary boring plan is documented and transmitted to the field crews by use of [Exhibit 6.3-I](#). [Exhibits 6.3-J](#), [6.3-K](#), [6.3-L](#) and [6.3-M](#) are used to document the materials encountered in the borings.

Soil samples and rock cores obtained represent a considerable investment of time and money. The samples should be properly labeled, transported and stored. A detailed treatment of procedures for handling and storing samples is provided in the *AASHTO Manual on Subsurface Investigations*. However, any method that satisfactorily protects a sample from shock, large temperature changes and moisture loss may be used. All containers used for storage should be identified with the following:

- project name and number,
- box number of total set,
- bore hole number, and
- applicable depth information.

The identification markings should be on the exterior as well as the interior of the storage container. Rock cores should be routinely photographed in color as soon as possible after being taken from the bore hole and before laboratory testing. All samples not used in laboratory testing should be retained until the proposed construction is completed and/or all claims are settled.

### 6.3.4 GEOPHYSICAL AND IN-SITU TESTS

Geophysical methods are used to gather information on subsurface geological features. Generally, geophysical methods are used as a reconnaissance investigation to cover large areas and/or to supplement information between bore holes. The methods given in [Exhibit 6.3-N](#) should be considered to determine when geophysical testing may provide an economical means of obtaining information. Many benefits may be obtained by the use of geophysical

tests, but specific procedures and limitations of the testing methods should always be considered. Additional information regarding geophysical investigations may be found at the [CFLHD website](#). Seismic refraction geophysical tests are used to provide preliminary subsurface information for the items below:

- planning detailed drilling investigations,
- writing project feasibility studies,
- engineering studies,
- estimating rippability of rock excavation (see [Exhibit 6.3-O](#)), and
- extending data between bore holes.

[Exhibit 6.3-P](#) is a form commonly used to collect field seismic information. Detailed field and analytical procedures can be found in Bison's *Handbook of Engineering Geophysics*, Volume I and II, respectively, as well as on the [CFLHD website](#). Seismic refraction can only be used to provide reliable information when subsurface strata become more dense with depth. When the subsurface strata are expected to violate this situation, electrical resistivity has provided good results on specific projects. Resistivity is somewhat more difficult to interpret but should be routinely considered. [Exhibit 6.3-Q](#) may be used to collect field data.

The most commonly used in-situ test for surface investigations is the Standard Penetration Test (SPT), AASHTO T 206-87(2000). Some common problems or procedural errors that can provide misleading results are given in [Exhibit 6.3-R](#). The use of automatic hammers for SPT is recommended if standard drop height and hammer weight can be maintained. SPT values obtained with automatic hammers should be calibrated by field comparisons with standard drop hammer methods. All SPT values should be corrected for overburden pressure. [Exhibit 6.3-S](#) provides empirical soil parameters from corrected SPT values for granular soils.

Another commonly used in-situ test is the Cone Penetrometer Test (CPT). This test can provide in-situ soil strength parameters and a differentiation between end bearing and side friction for pile design. The test can provide accurate and economical test results in soft to medium dense sands, silts and clays. Major drawbacks of CPT are that samples are not recoverable and that tests in dense and/or gravel deposits are difficult and may damage equipment. FHWA-SA-91-043 Manual entitled *The Cone Penetrometer Test* should be reviewed before field CPT is attempted. [Exhibit 6.3-T](#) is a form used to record field CPT data.

Other commonly used in-situ devices are vane shear tests and pressuremeter tests. *Geotechnical Engineering Investigation Manual* and *AASHTO Manual on Subsurface Investigations* provide additional details on these devices.

The following are types of specialized geotechnical instrumentation commonly in use:

- inclinometers,
- piezometers,
- displacement stakes,
- strain gauges, and
- earth pressure cells.

The *Geotechnical Instrumentation for Monitoring Field Performance* by Duncliff is a recommended reference for planning, designing and specifying instrumentation projects.

[Exhibits 6.3-U](#) and [6.3-V](#) are data collection sheets commonly used for field shear tests and inclinometer instrumentation.

### **6.3.5 LABORATORY TESTS**

After collecting soil and rock samples, laboratory tests are routinely performed to quantify material properties and verify design assumptions. The type and number of tests required are primarily a function of the variability of the site, the purpose of the investigation and the amount of risk and potential consequences of failure. Sufficient testing should be performed so that the geotechnical project engineer or geologist is satisfied that the test results are representative of in-situ conditions.

[Exhibit 6.3-W](#) provides a guideline for estimating laboratory test requirements for the different types of analysis. [Exhibit 6.3-W](#) is representative of past experience with projects and is not intended to limit either the type of laboratory test or the frequency of testing but to provide a starting point for evaluation. See the [\*Geotechnical Engineering Investigation Manual\*](#) for additional information.

Requesting and transmitting samples for laboratory testing and evaluation is handled differently in each FLH Division.

Clearly identify each sample with the following:

- project,
- bore hole or test pit number and location,
- depth of sample taken, and
- specific test requested.

All detailed test results should be included in the finalized geotechnical report. Care should be taken to ensure that only factual data is presented or that all interpretations of laboratory data are clearly identified as such.



Project Specifics	Information Sources
Type of proposed project. Proposed project termini. Funds available. Schedule requirements. Items requiring investigation. Local authorities to contact. Location and type of utilities present.	Planning and Coordination or Project Development Unit
Scope of investigation desired. Availability of equipment.	Geotechnical Engineer
Location of structures.	Structures/Bridge Unit
Site maps and field reference systems.	Location and/or Survey Unit
Specific site restriction such as water quality, environmental considerations, or client agency considerations.	Environmental Unit
Right-of-entry (access) restrictions.	Applicable property owners.

**Exhibit 6.3-A POSSIBLE SOURCES FOR SITE-SPECIFIC INFORMATION**

Preliminary Information for Geotechnical Investigations				
Project: _____		Date: _____		
Account Number: _____		Estimated quantity needed: _____		
Funding: _____		Information needed by: _____		
Type of Investigation? Structure   Foundation   Roadway   Slope Analysis   Materials Source   Landslide   Other _____				
Report Type? Preliminary   Final   Informal   Formal				
<b>Site Specific Information</b>				
Location: _____				
Termini: _____		To: _____		
Field Reference Available (stakes, MP, etc.): _____				
Terrain/Access? Easy   Moderate   Difficult   Very Difficult				
Utilities? Water   Electric   Telephone   Unknown				
Local Contacts:				
Agency Name: _____		Property Owner: _____		
Address: _____		Address: _____		
Telephone: _____		Telephone: _____		
<b>Additional Information Needed By Geotechnical</b>				
Mapping?   Not Available		Availability Date: _____		
<i>Structure Foundation Projects</i>				
Structure Type: _____		Bridge Spans (No. & Length) _____		
Max. Wall Height: _____		Max. Loads Expected: _____		
Availability of Preliminary Plans: _____				
Restrictions: _____				
Comments: _____				
<i>Roadway Projects</i>				
Type?	Overlay	Widening	Reconst.	New Alignment   Other
Pavement Surface Type: _____				
Traffic Data Availability:		Where? _____	When? _____	
Restrictions: _____				
Comments: _____				
<i>Material Source Projects</i>				
Use of Material?	A.C. Pavement	Base	Borrow	Other _____
Amount Needed: (m <sup>3</sup> ) (ft <sup>3</sup> )	_____	_____	_____	_____
Suggested Source: _____				
Previous Use: _____				
<i>Slope/Landslide Projects:</i>				
History/Maint. Problems: _____				
Estimated Max. Movement Per Year: _____				
Previous Correction Attempts: _____				
Initial Correction Concepts: _____				
<i>Estimated Number of Holes:</i>				
Depth: _____		Backhoe or Dozer work required? _____		
Is Water Available? _____		How Far? _____		
Estimated Conditions: _____				

**Exhibit 6.3-B PRELIMINARY GEOTECHNICAL INVESTIGATION FORM**

Type of Investigation	Use by Equipment Type									
	Hollow Stem Auger Drill	Large Core Drill	Small Core Drill	Seismic	Resistivity	Roughness and Deflection	Water Supply Equipment	In-Situ Strength Devices	In-Situ Monitors	Backhoe
<b>Roadway Soils</b>	1	1	2	2	3	3	2	3	3	1
<b>Foundations</b>	1	1	2	2	3	4	1	2	2	2
<b>Existing Pavement Evaluations</b>	1	2	1	4	4	1	1	4	4	3
<b>Material Sources</b>	1	1	2	2	3	4	1	3	3	1
<b>Landslides</b>	1	1	2	2	3	4	1	1	1	2
<b>Cutslopes</b>	1	1	2	2	3	4	1	3	2	1

Use Code:

1 = Frequently

3 = Seldom

2 = Occasional

4 = Usually Inappropriate

### Exhibit 6.3-C GENERAL INVESTIGATION EQUIPMENT REQUIREMENTS

Source	Type of Information	Description
USGS <i>Index of Publications</i> Superintendent of Documents US Government Printing Office Washington, DC 20402	water supply papers bulletins professional papers circulars annual reports monographs	General physical geology emphasizing all aspects of earth sciences, including mineral and petroleum resources, hydrology and seismicity, and groundwater resources.
USDOI Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092	index maps  quadrangle maps  topographic maps	Maps of each State showing coverage and sources of published geological maps.  Maps that support the older geological folios including aerial and bedrock maps.  Contour maps for all States.
Geological Society of America P. O. Box 9140 3300 Penrose Place Boulder, CO 80302	monthly bulletins special papers memoirs  geological maps	Specialized geological subjects and intensive investigations of local geology.  Maps of glacial deposits and Pleistocene Aeolian deposits.
USDA Soil Conservation Service <i>List of Published Soil Surveys</i> Washington, DC	Soil Maps and Reports	Surveys of surface soils described in agriculture terms, physical geology summarized, and excellent for highway or airfield investigations.
State Geological Surveys/ Geologist Offices	Geological Maps and Reports	Maps/reports covering specific areas or features in the publications of the State geologist.

### Exhibit 6.3-D SOURCES OF REGIONAL GEOTECHNICAL INFORMATION

<b>Exploration Method</b>	<b>General Use</b>	<b>Capabilities</b>	<b>Limitations</b>
Test Pits/ Shafts (Hand-Excavated).	Bulk sampling, in-situ testing, visual inspection.	Provides data in inaccessible areas, less mechanical disturbance of surrounding ground.	Expensive, time-consuming, limited to depths above groundwater level.
Test Pits/Trenches (Backhoe Excavated).	Bulk sampling in-situ testing, visual inspection, excavation rates, depth of bedrock and groundwater.	Fast, economical, generally less than 3 m (10 ft) deep, can be up to 6 m (20 ft) deep.	Equipment access, generally limited to depths above groundwater level, limited undisturbed sampling.
Drilled Shafts	Pre-excavation for piles and shafts, landslide investigations and drainage wells.	Fast, more economical than hand excavated, minimum 750 mm (30 in) diameter maximum 2 m (6.5 ft) diameter	Equipment access, difficult to obtain undisturbed samples casing may obscure visual inspection, and costly mobilization.
Dozer Cuts	Bedrock characteristics, depth of bedrock and groundwater level, rippability, increase depth capability of backhoes, level area for other exploration equipment.	Relatively low cost, exposures for geologic mapping.	Exploration limited to depth above groundwater level. High environmental disturbance.

### **Exhibit 6.3-E USE OF TRENCHING AND TEST PITS**

Type of Investigation	Number of Borings	Depth of Borings
<b>Structure Foundations</b>	Min. 1 boring per substructure unit.	<b>Continue borings:</b> <ol style="list-style-type: none"> <li>Through unsuitable foundation soils (e.g., peats, highly organic soils, soft fine-grained soils, loose coarse grained soils) into competent material of suitable bearing capacity; and</li> <li>To depth where added stress due to estimated footing load is less than 10% of the existing effective soil overburden stress; or</li> <li>Min. of 3 m (10 ft) into bedrock if bedrock is encountered at shallower depth as determined by 2.</li> </ol>
<b>Retaining Walls</b>	Min. 1 boring per wall. Additional borings spaced 15 to 60 m (50 to 200 ft). Some borings should be in front of and in back of wall.	Continue borings to depth of 2 times wall height or minimum of 3 m (10 ft) into bedrock.
<b>Bridge Approach Embankments Over Soft Ground</b>	When approach embankments are placed over soft ground at least 1 boring should be made at each embankment to determine the problems associated with stability and settlement of the embankment. Test borings at proposed abutment locations may serve both stability and structural investigations.	Same as established above for structure foundations:  Additional shallow explorations (hand auger holes) taken at approach embankment locations are an economical way to determine depth of unsuitable surface soils or topsoil.
<b>Cuts and Embankments</b>	Space borings or test pits every 60 m (200 ft) (erratic conditions) to 150 m (500 ft) (uniform conditions) with at least 1 boring taken in each separate land form.  For high cuts and fills (8 m (26 ft) or greater), it is desirable to have a min. of 2 borings along a straight line to establish geological cross section for analysis.	<b>Cuts</b> <ol style="list-style-type: none"> <li>In stable materials extend borings min. 1 m (3 ft) below proposed centerline grade.</li> <li>In weak soils, at or near proposed centerline grade, extend borings below grade to competent materials.</li> </ol> <b>Embankments</b> Continue borings to competent material or to depth of 2 times the embankment height.
<b>Landslides</b>	Min. 2 borings along a straight line to establish geologic cross section for analysis. Number of sections depends on extent of stability problem. For an active slide, place at least 1 boring above and below sliding area.	Extend borings to an elevation below active or potential failure surface and into competent stratum, or to a depth for which failure is unlikely because of geometry of cross section.  Bore holes used to install inclinometers must be extended to competent material below the slide movement.
<b>Material Sites (Borrow Sources, Pits and Quarries)</b>	Space borings or test pits on a grid pattern every 30 to 45 m or change of material.	Extend exploration to base of deposit or to depth required to provide needed quantity.
<b>Pavement Rehabilitation</b>	Min. 1 boring or test pit/km (mi) with additional exploration as needed to define changes in subgrade material, pavement section and distressed areas.	Extend depth to at least 0.6 m (2 ft) below expected subgrade.

\*Information obtained from drilling may be supplemented by geophysical investigations.

#### Exhibit 6.3-F GUIDELINES FOR GEOTECHNICAL DRILLING INVESTIGATIONS\*

<b>Boring Method</b>	<b>Procedure Utilized</b>	<b>Applicability</b>	<b>Typical uses</b>
<b>Auger Boring (AASHTO T 203)</b>	Hand or power operated augering with periodic removal of material. In some cases, continuous auger may be used requiring only one withdrawal. Changes indicated by examination of material removed, auger resistance, and penetration rate.	Probe investigations to bedrock and shallow disturbed soil samples (less than 6 m (20 ft) in depth).	Disturbed soil sampling. Determine depth of overburden.
<b>Hollow-stem Auger (AASHTO T 251)</b>	Power operated, hollow stem serves as a casing. Changes indicated by examination of material removed, auger resistance, and penetration rate.	General purpose for soils and other locations requiring a cased hole.	Disturbed and undisturbed soil sampling and in-situ testing. Foundations, cut and fill slopes, and landslide investigations.
<b>Rotary Drilling (AASHTO T 225)</b>	Power rotation of drilling bit as circulating fluid removes cutting from hole. Changes indicated by rate of progress, action of drilling tools and examination of cuttings in drilling fluid. Casing usually not required except near surface.	A method to advance borings through a variety of materials including large boulders and broken rock.	Drilling probes, horizontal drains and installing instruments.
<b>Wire-line Drilling</b>	Rotary type drilling method where the coring device is an integral part of the drill rod string which also serves as a casing. Core samples obtained by removing inner barrel assembly from the core barrel portion of the drill rod. The inner barrel is released by a retriever lowered by a wire cable through the drilling rod.	Efficient method of recovering core samples of rock.	Foundations, material sources and rock cut investigation. General rock coring.

**Exhibit 6.3-G TEST BORINGS — TYPES AND APPLICATION**

<b>Sand-Gravel Soils</b>
<p>SPT<sup>1</sup> (split-spoon) samples should be taken at 1.5 m (5 ft) intervals and at significant changes in soil strata.</p> <p>Continuous SPT samples are recommended in the top 4.5 m (15 ft) of borings made at locations where spread footings may be placed in natural soils.</p> <p>Representative SPT jar or bag samples should be laboratory classified for verification of field visual soil identification.</p>
<b>Silt-Clay Soils</b>
<p>SPT and “undisturbed” thin wall tube samples<sup>2</sup> should be taken at 1.5 m (5 ft) intervals and at significant changes in strata.</p> <p>SPT and tube samples may be alternated in same boring or tube samples may be taken in separate undisturbed boring.</p> <p>Representative SPT jar or bag samples should be laboratory classified for verification of field visual soil identification.</p> <p>Tube samples should be tested for consolidation (for settlement analysis) and strength (for slope stability and foundation bearing capacity analysis),</p> <p>Field vane shear testing is recommended for obtaining in-place shear strength of soft clays, silts and nonfibrous peats.</p>
<b>Rock</b>
<p>Continuous cores should be obtained in rock or dense deposits using double or triple tube core barrels.</p> <p>For foundation investigations, core a minimum of 3 m (10 ft) into the rock.</p> <p>Core samples should be evaluated for strength testing (unconfined compression) for foundation investigations and for rock quality tests for quarry investigations (aggregate or riprap).</p> <p>Determine percent core recovery and RQD<sup>3</sup> value for each core run and record in the bore log.</p>
<b>Groundwater</b>
<p>Record water level encountered during drilling, at completion of boring, and at 24 hours after completion of boring in the bore log (when possible).</p> <p>When water is used for drilling fluid, adequate time should be permitted after hole completion for the water level to stabilize (more than one week may be required). In impermeable soils, a plastic pipe water observation well may be installed to allow monitoring of the water level over a period of time.</p> <p>Artesian pressure and seepage zones, if encountered, should also be noted in the bore log.</p> <p>The top 300 mm (1 ft) or so for the annular space between water observation well pipes and the borehole wall should be backfilled with grout, bentonite or a sand-cement mixture to prevent surface water inflow which can cause erroneous groundwater level readings.</p>

Notes:

1. *Standard Penetration Test, AASHTO T 206-87(2000)*
2. *Thin-Walled Tube Sampling of Soils, AASHTO T 207-96(2000)*
3. *Rock Quality Designation, Deere 1968*

### Exhibit 6.3-H SAMPLING GUIDELINES



**Project** \_\_\_\_\_

**Account Number:** \_\_\_\_\_

**Driller:** \_\_\_\_\_ **Engr/Geol:** \_\_\_\_\_

[illegible]

### Exhibit 6.3-I PRELIMINARY BORING AND TESTING PLAN

### Exhibit 6.3-J SAMPLE BORING LOG

Sample Boring Log									
Project Name: WA FH101 Cascade Rd.						Boring No. 1	Date: 1/12/95	Sheet 1 of 1	
Boring Location: 30m Lt. of P-103 stake						Type of Boring		Auger	
Drill: CME 75			Driller: P. Sloan			Casing Used	N/A	Size	
Field Logged By: P. Sloan						Boring Began: 1/12/95		Completed: 1/12/95	
Revisions/Final By: D. Lofgren						Ground Elev.		Weather: Fair/Cold	
Run or Sample Number	Depth From: To: Meters (feet)	Core Length Recovered % Recovered	RQD Fracture Spacing	SPT Blows per 150 mm (6 in)	Lab Test Adjusted SPT (N') per 0.3 m (1 ft)	Water Depth:	5.8 m (19 ft)	5.8 m (19 ft)	6.4 m (21 ft)
						Date/Time	4 P.M. 1/12	7 A.M. 1/13	7 A.M. 1/17
Description: (Density, Color, Type, Moisture, Other)									
1	0 0.8 (2.6)	- -	— —		—				
2	0.8 (2.6) 1.2 (4)	0.4 —	— —	3 6 8	—				
3	1.2 (4) 2.3 (7.5)	- -	— —		—				
4	2.3 (7.5) 2.7 (9)	0.1 —	— —	12 50+	—				
5	2.7 (9) 4.6 (15)	1.2 63	0 10-50		—				
6	4.6 (15) 6.1 (20)	1.4 93	15 50-150		—				
7	6.1 (20) 7.6 (25)	1.5 100	75 75-200		—				
8	7.6 (25) 10.0 (33)	2.4 100	90 200+		—				

**Exhibit 6.3-J SAMPLE BORING LOG**  
(Continued)

<b>Soil Color</b>	<b>Color Code</b>
Brown	BR
Lt. Brown	LT BR
Dk. Brown	DK BR
Grey	GREY
Lt. Grey	LT GR
Dk. Grey	DK GR
Red	RED
Black	BLK
Blue	BLUE
Grey-Brown	GR BR
Grey-Red	GR RD
Brown-Red	BR RD
Yellow	YELL
Purple	PURP
Green	GREEN
White	WHITE
Grey-Green	GR GN
Mottled	MOTT
Orange	ORAN

\*See [Exhibit 6.3-M](#) for Field Classification for Soil and Rock.

**Exhibit 6.3-K BORING LOG TERMINOLOGY  
(Soil Color)**

Soil Description <sup>1</sup>	Terms
Soil Density, Consistency or Hardness	See <a href="#">Exhibit 6.3-M</a>
Color	See <a href="#">Exhibit 6.3-K</a>
Major Grain Size	The grain size that is > 50% of sample
Modifying Term	AND – 40% to 50% of minor grain size SOME – 10% to 40% of minor grain size TRACE – Less than 10% of minor grain size
Minor Grain Size	The next visible grain size.
Moisture Content	D – DRY M – MOIST W – WET
Laboratory Classification (i.e., AASHOT, Unified)	

*Notes:*

1. *The following provides an example of soil description:*

*Medium dense, reddish brown, silt, SOME fine sand, TRACE of Clay (MOIST), A-4.*

#### **Exhibit 6.3-L BORING LOG TERMINOLOGY (Soil Description)**

Particle Size Limits of Soil Constituents <sup>1</sup>		Cohesive Soils			Granular Soils		Rock Hardness <sup>4</sup>		Rock Quality <sup>3</sup>	
	Sieve Size	Consistency	Field Identification	Resistance <sup>3</sup> By SPT	Relative Density	Resistance <sup>3</sup> By SPT	Hardness	Field Identification	Structural Quality	RQD <sup>5</sup>
<b>Boulder (BLDR)</b>	305 mm +	<b>Very Soft (S1)</b>	Easily penetrated 100 to 150 mm by fist	0-1	<b>Very Loose</b>	0-4	<b>Very Soft (R1)</b>	Crumbles under firm blows with point of geological pick. Can be peeled by a pocket knife.	<b>Very Poor</b>	0-25%
<b>Cobble (COBB)</b>	75-305 mm	<b>Soft (S2)</b>	Easily penetrated 50 to 75 mm by thumb	2-4	<b>Loose</b>	5-10	<b>Soft (R2)</b>	Can be peeled by a pocketknife with difficulty, shallow indentations made by firm blow of geological pick.	<b>Poor</b>	25-50%
<b>Gravel (GR)</b>	2-75 mm	<b>Firm (S3)</b>	Can be penetrated 50 to 75 mm by thumb with moderate effort	5-8	<b>Medium Dense</b>	11-24	<b>Medium Hard (R3)</b>	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of hammer end of geological pick.	<b>Fair</b>	50-75%
<b>Sand (SA)</b>	0.075-2 mm	<b>Stiff (S4)</b>	Readily indented by thumb but penetrated only with great effort	9-15	<b>Dense</b>	25-50	<b>Hard (R4)</b>	Specimen required more than one blow with hammer end of geological pick to fracture it.	<b>Good</b>	75-90%
<b>Silt (SI)</b>	Smaller than 0.075 mm (nonplastic)	<b>Very Stiff (S5)</b>	Readily indented by thumbnail	16-30	<b>Very Dense</b>	50 +	<b>Very Hard (R5)</b>	Specimen required many blows of hammer end of geological pick to fracture it.	<b>Excellent</b>	90-100%
<b>Clay (CL)</b>	Smaller than 0.075 mm (plastic)	<b>Hard (S6)</b>	Indented with difficulty by thumbnail	31 +			<b>Extremely Hard (R6)</b>	Specimen can only be chipped with geological pick		
<b>Notes:</b> <sup>1</sup> ASTM D653 <sup>2</sup> ASTM D2113 <sup>3</sup> Standard penetration test, AASHTO T-206-87(2000), No. of blows 0.3 m, N corrected for overburden pressure (N) <sup>4</sup> Douglas Piteau, 1977 <sup>5</sup> Rock quality designation, percent of core run 100 mm or greater in length.										

**Exhibit 6.3-M FIELD CLASSIFICATIONS FOR SOIL AND ROCK**  
(Metric)

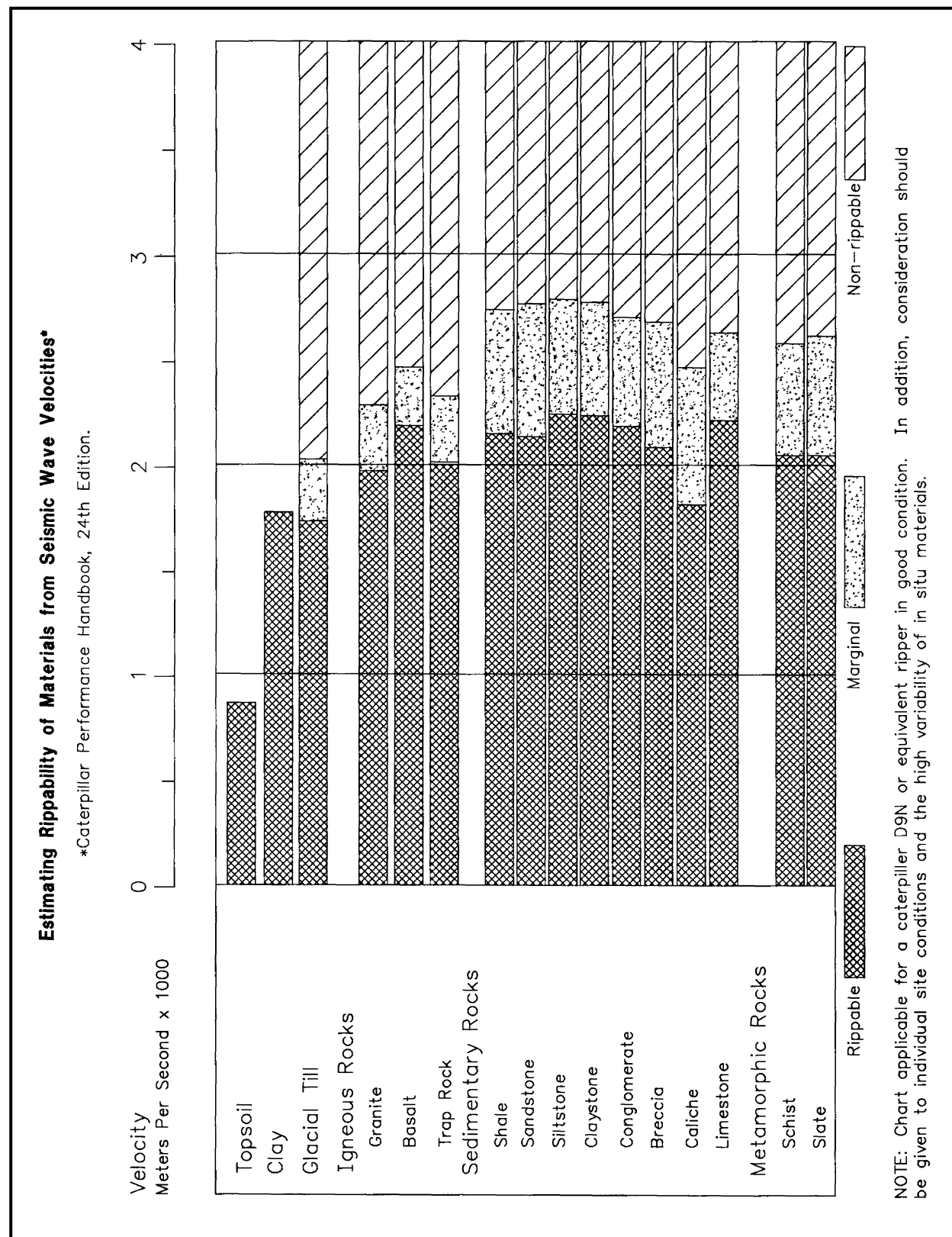
*To Be Provided*

**Exhibit 6.3-M FIELD CLASSIFICATIONS FOR SOIL AND ROCK  
(US Customary)**

Method	Basic Properties and Measurements	Applications	Frequency of Use
Seismic Refraction	Density and elasticity of subsurface material as measured by velocities of compression waves.	Estimate depth of more competent materials underlying less competent material. Interpolate subsurface condition between bore holes.	Common
Electrical Resistivity	Electrical conductivity of subsurface materials as measured by apparent resistance.	Identify layers of less competent material laying below more competent layers. Interpolate surface condition between bore holes	Occasional
Induced Polarization	Electrochemical properties or rock particles and ion concentrations in pore fluids measured by polarization voltages.	Identify location and concentration of potentially environmentally harmful rock material (primarily iron sulfides).	Rare
Ground Penetrating Radar	Dielectric interfaces related to the mechanical and geologic properties of subsurface materials are detected by high frequency radar pulses.	Identify soil horizons, the groundwater surface, soil/rock interfaces, man-made buried objects, and strata inclinations.	Seldom

**Exhibit 6.3-N GUIDELINES FOR USING GEOPHYSICAL METHODS**





**Exhibit 6.3-O ESTIMATING RIPPABILITY OF MATERIALS  
FROM SEISMIC WAVE VELOCITIES\***  
(Metric)

*To Be Provided*

**Exhibit 6.3-O ESTIMATING RIPPABILITY OF MATERIALS  
FROM SEISMIC WAVE VELOCITIES\*  
(US Customary)**

<b>Seismograph Data Sheet</b>															
Project Name:					Operator:					Date :					
Location Description :															
Field Notes :															

Distance (Meters)

0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
30	28	26	24	22	20	18	16	14	12	10	8	6	4	2	0
0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
60	56	52	48	44	40	36	32	28	24	20	16	12	8	4	0

**Exhibit 6.3-P SEISMOGRAPH DATA SHEET  
(Metric)**

*To Be Provided*

**Exhibit 6.3-P SEISMOGRAPH DATA SHEET  
(US Customary)**

**Project Name:** \_\_\_\_\_ **Date:** \_\_\_\_\_

Location Description: \_\_\_\_\_ Operator: \_\_\_\_\_

Notes: \_\_\_\_\_

$$\text{Apparent Resistivity} = (\text{Electrode Spacing}) (\text{Dial Reading}) (\text{Scale Factor})$$
[illegible]

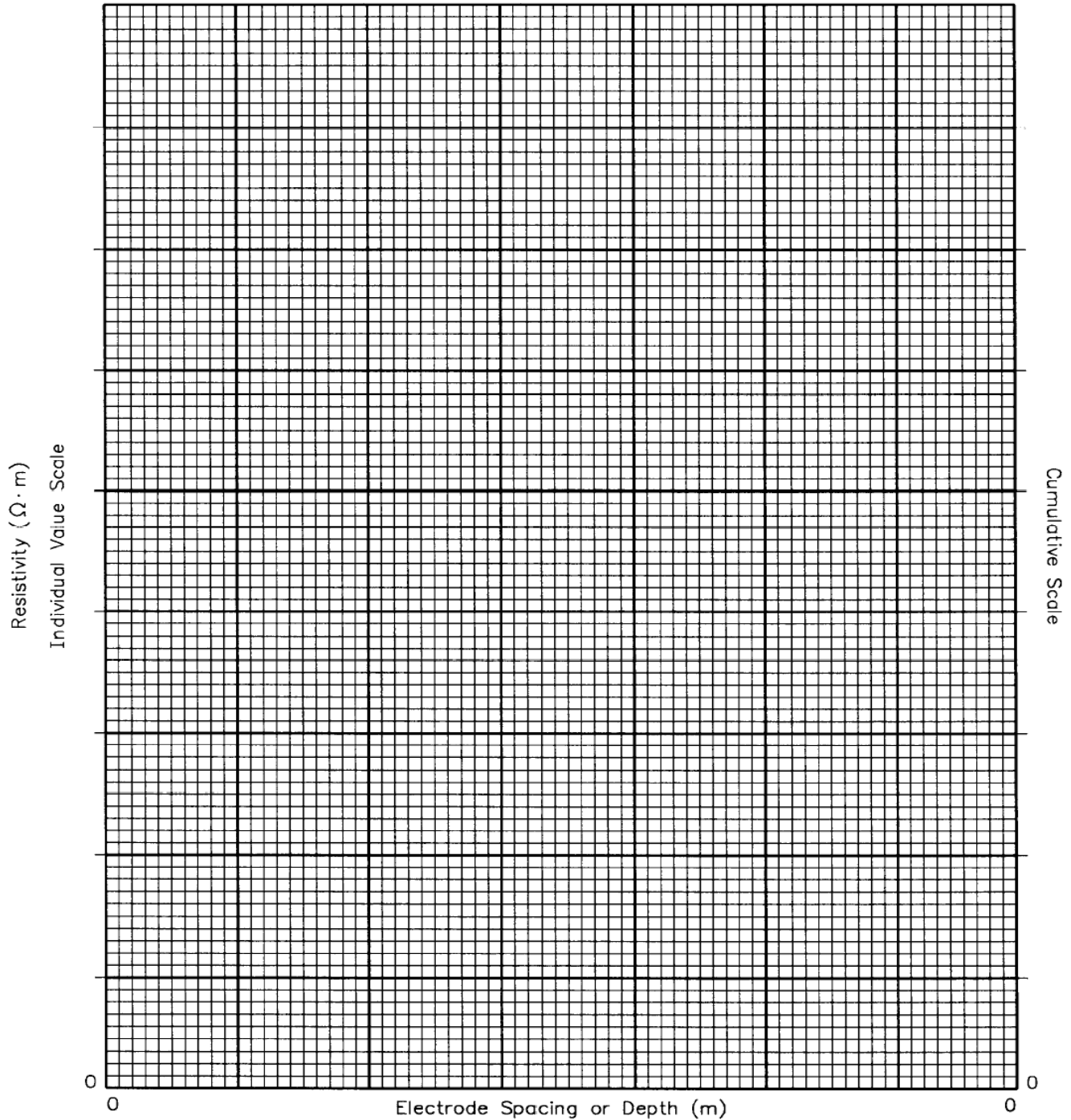
### Exhibit 6.3-Q RESISTIVITY DATA SHEET

**Resistivity Data Sheet (continued)**

Project Name: \_\_\_\_\_ Test No.: \_\_\_\_\_

Test Location: \_\_\_\_\_

Test Date: \_\_\_\_\_

**Exhibit 6.3-Q RESISTIVITY DATA SHEET (Metric)**  
(Continued)

*To Be Provided*

**Exhibit 6.3-Q RESISTIVITY DATA SHEET (US Customary)**  
(Continued)

Problem	Circumstance/Cause
Inadequate cleaning and/or seating of sampler.	Sludge and debris trapped in sampler or in bottom of hole, possibly from heaving sands.
Failure to maintain adequate hydrostatic pressure and/or over washing ahead of casing.	Fill-up inside casing. Disturbance of in-situ material. Too large of a pump.
Use of damaged and/or inadequate equipment.	Tip of sampler damaged by heavy driving. Drive weight nonstandard or does not strike drive cap evenly.
Hammer does not free-fall and/or correct height of fall is not maintained.	More than 1.5 turns around cat head or wire line will restrict fall. Proper height is not maintained by operator.
Operator and/or inspector errors.	Incorrect blow count. Incorrect location and/or depth. Sampler overdriven.

**Exhibit 6.3-R COMMON PROCEDURAL ERRORS USING STANDARD PENETRATION TEST**

Description	Very Loose	Loose	Medium	Dense	Very Dense	
Relative Density, D <sub>r</sub>	0	0.15	0.35	0.65	0.85	1.00
Corrected Standard Penetration No. N'	4	10	30	50		
Approximate Angle of Internal Friction ϕ***	25-32°	27-32°	30-35°	35-40°	38-43°	
Approximate Range of Moist Unit Weigh kN/m <sup>3</sup>	10.8-15.7	13.7-17.7	16.7-20.6	16.7-21.5	20.6-23.5	

Notes:

1. The table provides empirical values for ( $\phi$ ), Relative density ( $D_r$ ) and unit mass ( $\gamma$ ) of granular silts based on corrected  $N'$  (Correlations may be unreliable in silts containing gravel.)
2. For  $\phi$ , use larger values for granular material with 5% or less fine sand and silt.

**Exhibit 6.3-S EMPIRICAL VALUES, RELATIVE DENSITY AND MASS DENSITY OF GRANULAR SOILS\* (Metric)**



*To Be Provided*

**Exhibit 6.3-S   EMPIRICAL VALUES, RELATIVE DENSITY AND MASS DENSITY OF  
GRANULAR SOILS\*  
(US Customary)**

*To Be Provided*

**Exhibit 6.3-T SAMPLE CONE PENETROMETER TEST (CPT) DATA FORM (RESERVED)**

### Bore Hole Shear Test

*Project:* \_\_\_\_\_ *Boring No:* \_\_\_\_\_ *Test No:* \_\_\_\_\_

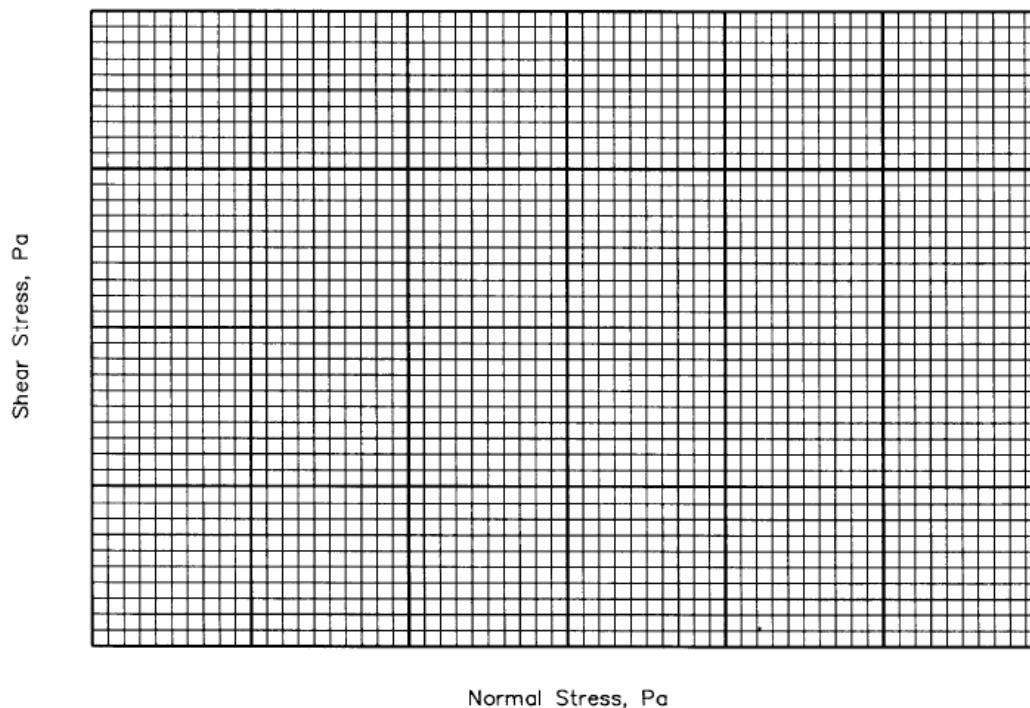
*Location:* \_\_\_\_\_ *Date:* \_\_\_\_\_

*Depth:* \_\_\_\_\_ *Tested By:* \_\_\_\_\_

*Description:* \_\_\_\_\_

Point No.	Normal Stress		Shear Stress		Time*	Remarks
	Gage	$\sigma_n$	Gage	$\tau_{max}$		

\*Consolidation time



**Exhibit 6.3-U BORE HOLE SHEAR TEST**

### Exhibit 6.3-V INCLINOMETER DATA

Test Analysis Type	Laboratory Tests Selection Frequency									
	A	B	C	D	E	F	G	H	I	J
Roadway Soil	F	F	F	R	F	F	L	L	R	L
Structural Foundation	F	M	F	R	R	R	M	M	M	M
Retaining Wall	F	M	F	R	LR	R	M	M	M	M
Pavement Design	F	F	F	R	FL	F	R	R	R	R
Material Source	F	F	F	R	M	M	R	L	R	R
Landslides	F	F	F	M	L	R	M	F-M	M	L

*Test Description:*

- A — Classification (Gradation and Atterberg Limits) AASHTO T11, T22, T88, T89, T90, T100
- B — Fine Grain Analysis AASHTO T88
- C — Atterberg Limits AASHTO T89, T90
- D — Permeability Tests AASHTO T215
- E — Remolded Density AASHTO T180 or T99
- F — R-Value/CBR AASHTO T190, T193, T292, T294<sub>r</sub>
- G — Unconfined Compression AASHTO T 208
- H — Direct Shear AASHTO T 236
- I — Triaxial AASHTO T296, T297
- J — Consolidation AASHTO T216

*Selection Legend:*

- F — Frequent/Routine Use
- M — Moderate Use
- L — Limited Use
- R — Rarely Used

**Exhibit 6.3-W GUIDELINES FOR SELECTION OF LABORATORY TESTS**

## 6.4 GEOTECHNICAL ANALYSIS

An engineering analysis combines the information obtained from the geotechnical field investigation and the laboratory test results to determine the engineering properties and drainage characteristics of the subsurface materials. In addition, the analysis should alert designers, contractors and construction personnel of potential problems and provide economical solutions with consideration given to alternatives. Finally, the analysis should provide an assessment of risk associated with each of the possible solutions. This Section does not give detailed textbook solutions to engineering problems but will provide general guidelines, potential pitfalls of these guidelines and specific references to assist the engineer in performing a detailed analysis.

The quality of the analysis depends on several factors. Knowledge of engineering principles and practical experience in application of these principles is of course very important; but a thorough analysis cannot be accomplished without a clear understanding of the details of the proposed project. This understanding requires a flow of communication and information between project development, bridge design, planning and coordination and the geotechnical engineer. To provide an acceptable analysis of geotechnical information that is practical, economical and of sufficient detail, final alignment and grade are necessary. The project development process must incorporate sufficient time to allow proper investigation and analysis.

At a minimum, the geotechnical analysis should result in a subsurface profile of the project with design soil strength parameters and an engineering evaluation of the subsurface conditions.

The following Sections address the types of projects typical of the Federal Lands Highway Divisions. Within each Section, an outline of typical geotechnical procedures with references to appropriate Exhibits is provided to focus on the more pertinent items. It is beyond the scope of this Chapter to address all details of analysis performed by the Geotechnical Unit. These outlines are only provided to ensure that basic geotechnical items are consistently considered.

### 6.4.1 ROADWAY SOILS

The vast majority of FLH projects require a roadway investigation. These guidelines presented may be applied to all lengths of roadway projects but the frequency of testing and sampling should be adjusted based upon site specific problems and practical engineering judgment. The following steps provide the basic procedure for typical projects. Sources for site-specific information and detailed references are provided. Typical sample forms are provided that may be used as part of the investigation and analysis process. The following applies:

1. **Initiate Project.** The following applies:
  - a. Identify available preliminary information (see [Exhibit 6.3-B](#)).
  - b. Obtain or review other pertinent preliminary project development information (e.g., engineering study reports, location study reports, environmental impact documents, design scoping reports). Refer to [Chapter 4](#) for this information.

- c. Obtain preliminary design information and plans showing the location of proposed cuts and fills, retaining walls, structures, preliminary earthwork quantities, borrow and aggregate needs.
2. **Review Available Geotechnical Data.** The following applies:
  - a. Review any geotechnical reports and information for projects in the vicinity with emphasis placed on projects on the same route.
  - b. Review published information (see [Exhibit 6.3-D](#)).
  - c. Obtain survey information (e.g., cross sections, drawings, plans).
3. **Plan Field Investigation.** Before performing the field investigation, obtain the following information:
  - a. Determine drilling requirements (see [Exhibit 6.3-F](#)).
  - b. Review checklists for site investigations (see [Exhibit 6.4-A](#)) and roadway cuts and embankments (see [Exhibit 6.4-B](#)) to identify needed information to be collected.
  - c. Determine preliminary equipment requirements (see [Exhibits 6.3-C](#), [6.3-E](#), [6.3-G](#) and [6.3-M](#)).
  - d. Determine site restrictions and revise equipment requirements. A site visit may be required.
  - e. Develop a preliminary boring and testing plan (see [Exhibit 6.3-I](#)).
4. **Plan Sampling and Testing.** The following applies:
  - a. Determine sampling and testing requirements (see [Exhibits 6.3-C](#), [6.3-F](#) and [6.3-H](#)).
  - b. Record field information (see Exhibits [6.3-J](#), [6.4-C](#), [6.4-D](#), [6.4-G](#), [6.4-H](#) and [6.4-O](#) through [6.4-W](#), as applicable).
5. **Summarize Field Data.** The following applies:
  - a. Summarize soil survey information ([Exhibit 6.4-D](#)) and water problem areas ([Exhibit 6.4-E](#)).
  - b. Determine appropriate shrink/swell factors ([Exhibit 6.4-F](#)).
  - c. Summarize soil profile information (see [Exhibits 6.4-G](#) and [6.4-H](#)).
6. **Perform Analysis and Write Report.** Conduct the following:
  - a. Review the roadway cut and embankment checklist ([Exhibit 6.4-B](#)) to ensure all appropriate information is available.

- b. Draft a report according to the guidelines presented in [Section 6.6.1](#).
- c. Refer to the general report checklist ([Exhibit 6.4-I](#)) and the site investigation checklist ([Exhibit 6.4-A](#)) to ensure appropriate report content.
- d. Finalize the report.

On longer projects, the sampling frequency may be reduced. Therefore, more emphasis needs to be placed on carefully inspecting and assembling the field information and laboratory test results to determine sections of roadway with similar characteristics. The characteristics that are of primary importance are in-situ material properties and existing conditions. Other items (e.g., proposed use, surface and subsurface water, vertical and horizontal alignment (cut/fill)) can also influence the analysis. The selection of the grouping factors used to identify similarities is usually determined by problems that are likely to be encountered on a specific project. Obviously, this type of analysis requires practical experience for effective implementation. [Exhibit 6.4-J](#) provides some guidance in selecting detailed factors and conditions that may be used. [Exhibit 6.4-F](#) may be used to estimate unit weights and shrink/swell factors.

After determining areas with similar conditions and material, engineering properties are assigned to materials for evaluation and design. These properties are determined either from direct laboratory tests or from correlated and/or assumed properties from manuals or textbooks referenced in [Section 6.2](#). The analysis of a roadway soil investigation should concentrate on defining area limits and the severity of the following problems and conditions:

- establish design cut and fill slope ratios;
- locate suitable materials for embankments, topping, subbase, base, select backfill, topsoil, riprap or other roadway materials as applicable;
- identify shrink/swell factors for excavation;
- identify areas requiring subexcavation;
- identify areas of poor soils to be wasted or not used in the top layer of embankments;
- locate wet areas (e.g., seepage of excessive water);
- identify potential areas of instability; and
- determine the subgrade strength values for pavement structure design.

## 6.4.2 STRUCTURE FOUNDATIONS

One of the most critical steps in analyzing structural foundations is the selection of foundation types that are applicable to specific site conditions. To systematically select or eliminate types of foundations, the following steps should be considered:

1. **Identify.** Identify the type of superstructure and loads to be applied to the foundation. Coordinate with the Structural Design Unit for this information; refer to [Chapter 10](#).



2. **Define.** Define and summarize subsurface conditions.
3. **Assess.** Subjectively assess the applicability of each type of foundation for their capability of carrying the required loads and estimate the amount of settlement that is likely.
4. **Eliminate.** Eliminate obviously unsuitable foundation types and prepare detailed studies and/or tentative designs for new foundations.
5. **Recommend.** Refer to [Exhibit 6.4-K](#) for a summary of applicable soil conditions for different foundation types. Select and recommend the foundation type that meets structure requirements and is best suited and most economical for site subsurface conditions.
6. **Perform Analysis.** Perform an analysis to provide the structural designer with at least the following information:
  - Recommended foundation type and bottom of footing or pile tip elevations.
  - Ultimate bearing capacity of foundation unit and recommended allowable or design value with appropriate factors of safety.
  - Limitations and/or potential problems with the recommended foundation type.
  - Suitable alternative foundation types.
  - Potential construction problems and recommended construction control measures.

Recommended minimum and typical ranges for factor of safety for the geotechnical soil substructure interaction are as follows:

1. **Shallow Foundations.** For shallow foundations, the factors of safety are:

Bearing Capacity	—	3.0
Sliding Along Base	—	1.5
Overtopping (Rotational Failure)	—	2.0

2. **Deep Foundations.** For deep foundations, the factors of safety are:

Driven Piles (Static Method)	—	2.0 to 3.0
Drilled Shafts	—	2.0 to 2.5

[Exhibits 6.4-L](#) and [6.4-M](#) illustrate samples of forms that are used to present allowable bearing capacities. In addition, settlement criteria should be established for specific subsurface conditions and structural requirements. The typical settlement criteria is a maximum 40 (1.5 in) to 50 mm (2 in) settlement that corresponds to 20 (0.75 in) to 25 mm (1 in) differential settlement between substructure units at allowable structural loadings.

The Geotechnical Unit is also responsible for ensuring that pile foundations can be installed to the design requirement without damage. In situations where concrete piles, high loads or difficult installation is anticipated, dynamic pile analysis is often performed. The wave equation computer program is often used to establish installation equipment requirements and pile stress during construction. As an alternative and/or supplement to the wave equation, dynamic pile monitoring during actual installation may be used. Detailed information on these procedures, along with other detailed structural foundation analysis techniques and design procedures, are provided in the FHWA *Soils and Foundation Workshop Manual* and the *Manual on Design and Construction of Driven Pile Foundations*.

Structure foundation investigations are usually confined to the area of the substructure units. Open communication and a close working relationship with the structural design engineer is required to provide an efficient, cost-effective analysis of foundations. The following provides the basic procedural steps for a typical structural geotechnical investigation:

1. **Initiate Project.** The following applies:
  - Identify available preliminary information (see [Exhibit 6.3-A](#)).
  - Obtain or review other preliminary pertinent project development information from the Programming and Coordination Unit or the Project Development Unit, as applicable.
2. **Review Available Geotechnical Data.** The following applies:
  - Review as-constructed plans for any existing structure at or near the proposed project site.
  - Review any geotechnical reports and subsurface information for structures in the vicinity of proposed site.
  - Review published information (see [Exhibit 6.3-C](#)). Place emphasis on localized geological and USDA soil survey information.
  - Obtain a bridge layout sheet from the Bridge Unit.
3. **Plan Field Investigation.** The following applies:
  - Determine drilling requirements (see [Exhibit 6.3-F](#)).
  - Review the checklist for site investigation (see [Exhibit 6.4-A](#)) to identify the needed information to be collected.
  - Discuss structure type and foundation requirements with the bridge engineer.
  - Determine preliminary equipment requirements (see [Exhibits 6.3-C](#), [6.3-E](#), [6.3-G](#) and [6.3-M](#)).
  - Determine site restrictions. A site visit may be required.

- Develop a preliminary boring and testing plan (see [Exhibit 6.3-I](#)).
4. **Plan Sampling and Testing.** The following applies:
- Determine sampling and testing requirements (see [Exhibits 6.3-C](#), [6.3-F](#), [6.3-H](#) and [6.3-W](#)).
  - Make preliminary selection of applicable foundation types (see [Exhibit 6.4-K](#)).
  - Record field information (see [Exhibits 6.3-J](#), [6.4-C](#), [6.4-D](#), [6.4-H](#), [6.4-A](#) and [6.4-N](#) through [6.4-V](#) as applicable).
5. **Summarize Field Data.** The following applies:
- Review [Exhibit 6.3-S](#) and [Exhibit 6.4-A](#).
  - Summarize soil profile information (see [Exhibits 6.4-G](#) and [6.4-H](#)).
6. **Perform Analysis and Write Report.** The following applies:
- Review checklist items for spread footings ([Exhibit 6.4-M](#)), piles ([Exhibit 6.4-O](#)) and drilled shafts ([Exhibit 6.4-P](#)), as applicable.
  - Provide allowable bearing pressure ([Exhibit 6.4-L](#)) and pile capacity ([Exhibit 6.4-M](#)), as applicable.
  - Refer to the General Report Checklist ([Exhibit 6.4-I](#)) and the Site Investigation Checklist ([Exhibit 6.4-A](#)) to ensure appropriate report content.
  - Finalize the report.

### 6.4.3 RETAINING WALLS

Retaining walls are a specialized structure; therefore, comments and guidelines given in this Section are relevant to retaining wall analysis. This Section provides the basic procedural steps, thought process and initial source of reference and standard forms for a typical geotechnical retaining wall investigation. Many different wall types are available. See [Section 9.4.4](#) and [Section 10.4.12](#) for retaining wall designs.

Coordinate with the Highway Design and/or Structural Design units for selection of retaining wall type and location. The wall selection type and location may be made during the conceptual and preliminary design phase (refer to [Chapter 4](#)) or the final design phase (refer to [Chapter 9](#)).

The numerous proprietary wall designs require review and comparisons of specific wall design parameters. When proprietary wall designs are suitable for specific site conditions, alternative bid procedures are recommended. To ensure that these alternatives are equal, a review by the Geotechnical Unit prior to the advertisement of the construction contract is required. Designs submitted for approval must contain all calculations and assumptions made by the proprietary wall design. Include with the submittal, copies of any computer programs used. The computer

programs must be in a format compatible with government equipment. Major points of comparison will include but are not restricted to the following items:

- design life,
- maximum total and differential settlements,
- maximum stress in wall members,
- magnitude and direction of external loads,
- surface and subsurface drainage required,
- backfill quantity and quality requirements, and
- previous experience with other highway applications.

An overview of the basic retaining wall fundamentals and procedures can be reviewed in the *Forest Service's Retaining Wall Design Guide* and in the FHWA *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines*. Manufacturers' design charts should only be used as preliminary estimates, and final wall design should be checked by the geotechnical staff. When information is not provided or is unsubstantiated, Rankine analysis and conservative values should be used. See [Section 10.4.12](#) for safety factors and other critical design elements applicable to walls. In addition, consider the following when analyzing retaining wall foundation and backfills:

- do not include material in the upper 1.5 m (5 ft) in front of the wall when evaluating resistance to sliding along the base and overturning;
- the resultant of all forces acting on the wall should fall within the middle third of the base;
- live loads due to temporary construction activities (e.g., materials, equipment) and traffic loading should be in the order of 11 kPa (1.5 lbs/in<sup>2</sup>) to 17 kPa (2.5 lbs/in<sup>2</sup>);
- avoid backfill material (e.g., silts and clays unless special precautions and analyses are made to account for these materials);
- evaluate expected settlements to ensure that their magnitudes are consistent with the rigidity of the type of wall selected; and
- evaluate subsurface and surface drainage requirements and include any specifications in the geotechnical analysis and recommendation.

The following provides the basic procedures for a typical geotechnical retaining wall investigation:

1. **Initiate Project.** The following applies:
  - Identify available preliminary information (see [Exhibit 6.3-A](#)).
  - Determine specific site requirements (e.g., wall location, heights, aesthetic restrictions).
2. **Review Available Geotechnical Data.** The following applies:

- Review any geotechnical reports and information for project location.
- Review published information (see [Exhibit 6.3-D](#)).
- Review *Geotechnical Engineering Notebook* retaining wall chapters.
- Obtain survey information (e.g., cross sections, plans) from the Design Unit.

3. **Plan Field Investigation.** The following applies:

- Determine drilling requirements (see [Exhibit 6.3-F](#)).
- Review checklists for site investigations ([Exhibit 6.4-A](#)) and retaining walls ([Exhibit 6.4-Q](#)) to identify needed information to be collected.
- Determine preliminary equipment requirements (see [Exhibits 6.3-C](#), [6.3-E](#) and [6.3-G](#)).
- Determine site restrictions and revise equipment requirements. A site visit may be required.
- Develop a preliminary boring and testing plan (see [Exhibit 6.3-I](#)).

4. **Plan Sampling and Testing.** The following applies:

- Determine sampling and testing requirements (see [Exhibits 6.3-F](#), [6.3-H](#) and [6.3-W](#)).
- Record field information ([Exhibits 6.3-J](#), [6.3-P](#), [6.3-Q](#), [6.3-U](#), [6.3-V](#) and [6.4-C](#), as applicable).

5. **Summarize Field Data.** The following applies:

- Review [Exhibit 6.3-S](#) and [Exhibit 6.4-A](#).
- Review checklists for general report ([Exhibit 6.4-I](#)) or site investigation ([Exhibit 6.4-A](#)), as appropriate.

6. **Perform Analysis and Write Report.** The following applies:

- Review checklists for retaining walls ([Exhibit 6.4-Q](#)) and spreadfootings ([Exhibit 6.4-N](#)), piles ([Exhibit 6.4-O](#)) or drilled shafts ([Exhibits 6.4-P](#)), if applicable.
- Provide allowable bearing pressure ([Exhibit 6.4-L](#)) and pile capacity ([Exhibit 6.4-M](#)), as applicable.
- Write draft report.

- Refer to the General Report Checklist ([Exhibit 6.4-I](#)) and the Site Investigation Checklist ([Exhibit 6.4-A](#)) to ensure appropriate report content.
- Finalize report.

#### 6.4.4 PAVEMENT DESIGN

The pavement design procedures used by FLH Divisions use empirical data developed from AASHTO road tests that are modified by experience gained from pavements built for use on Federally owned lands. The concepts are based upon procedures presented in the AASHTO *Interim Guide for Design of Pavement Structures*. It is anticipated that the new concepts and procedures presented in the 1993 AASHTO *Guide for Design of Pavement Structures* will eventually be incorporated into the Federal Lands Highway pavement design procedures. Until that time, correlation between the existing procedures and the new procedures presented in the new AASHTO *Manual* is encouraged to establish a database for the purpose of confirming the reliability, standard deviation and changes in serviceability input parameters required by the new procedures.

Pavement designers should familiarize themselves with the DARWIN computer program. This Program incorporates the design procedures provided in the AASHTO *Guide for Design of Pavement Structures* 1993.

Generally, only flexible pavements are built by FLH Divisions and therefore this section will deal primarily with flexible pavement design procedures. Where rigid pavements are required and designed, follow the procedures and guidelines used in the AASHTO *Design of Pavement Structures*.

The following provides the basic procedural steps, initial sources of reference materials and standard forms for a typical pavement design investigation:

1. **Initiate Project.** The following applies:

Identify available preliminary information (see [Exhibit 6.3-A](#)).

- Obtain project-related restrictions (e.g., costs, aesthetics, environmental) imposed by others by reviewing preliminary project development information.
- Obtain pavement design data (traffic count, classification and frost depth, etc.)

2. **Review Available Geotechnical Data.** The following applies:

- Review any geotechnical reports and information for project location.
- Review published information (see [Exhibit 6.3-D](#)).
- Determine thickness of the existing pavement and identify initial design material properties.

3. **Plan Field Investigation.** The following applies:

- Determine drilling requirements (see [Exhibit 6.3-F](#)).
  - Review the Pavement Design Checklist ([Exhibit 6.4-R](#)) to identify needed information to be collected.
  - Determine preliminary equipment requirements (see [Exhibits 6.3-A](#), [6.3-E](#) and [6.3-G](#)).
  - Develop a preliminary boring and testing plan (see [Exhibit 6.3-I](#)).
4. **Plan Sampling and Testing.** The following applies:
- Determine sampling and testing requirements (see [Exhibits 6.3-F](#), [6.3-H](#), [6.4-J](#) and [6.4-S](#)).
  - Record field information ([Exhibits 6.4-T](#) and [6.4-U](#) and [6.4-V](#), as applicable).
5. **Summarize Field Data.** The following applies:
- Review [Exhibits 6.4-S](#) and [6.4-W](#).
  - Summarize soils and other data as appropriate (see [Exhibits 6.4-D](#), [6.4-E](#), [6.4-G](#) and [6.4-H](#)).
  - Prepare [Exhibit 6.4-G](#) or [6.4-H](#) and [6.4-D](#) or [6.4-E](#), as applicable.
6. **Perform Analysis and Write Report.** The following applies:
- Review the pavement design checklist ([Exhibit 6.4-R](#)) to ensure all appropriate information is available.
  - Document the pavement design parameters ([Exhibits 6.4-X](#), [6.4-Y](#) and [6.4-Z](#)), as applicable.
  - Write draft report.
  - Refer to the General Report Checklist ([Exhibit 6.4-I](#)) and the Site Investigation Checklist ([Exhibit 6.4-A](#)) to ensure appropriate report content.
  - Finalize report.

#### 6.4.4.1 New and Reconstructed Pavement Design

The information provided in this Section should be considered a guideline and is subject to revisions and deviation based upon new developments and sound engineering judgment. The design of new flexible pavements requires the following:

1. **Traffic Data Analysis.** Detailed analysis of traffic requires loadometer data and breakdown of annual daily traffic for specific vehicle types and axle arrangements.

Detailed examples of the procedures are given in Appendix C.2 of the AASHTO *Interim Guide for Design of Pavement Structures*. This type of information is not often available on FLH roads. Therefore, simplified traffic analysis is often used. Annual Daily Traffic (ADT) is estimated and the estimated percentage of major vehicle types is combined with Equivalent 80 kN (18,000 lbs) Axle Loads (EAL) to determine an EAL/day to represent all traffic data. Typical EAL values for common vehicles are:

- Automobile — 0.0004,
- Recreation Vehicle — 0.20,
- Light Truck — 0.20,
- Heavy Maintenance Truck — 0.60,
- Logging Truck — 2.30, and
- Bus — 0.88

In lieu of other data, typical values used in traffic analysis for FLH pavements are 20 year design periods and two-percent growth factors and minimum 5 EAL/days.

2. **Existing Soils Strength Determinations.** Existing subgrade soil strengths are evaluated by using the soil support correlation values. Three acceptable methods of obtaining soil support values are listed:

- three-point (CBR) test,
- Resilient Modulus ( $M_r$ ) test, and
- HVEEM Resistance (R) test.

The design soil support values can be determined from a percentile evaluation, an average or a minimum value, depending upon the situation and allowable risk of premature or localized pavement distressed areas. However, it is recommended that the 80<sup>th</sup> percentile and [Exhibit 6.4-W](#) be used to determine soil support values. Use the following soil support values and corresponding soil type as a general guide for subgrade soil conditions:

- poor soils — 0 – 4,
- medium soils — 4 - 6.5, and
- good soils — 6.5 – 10

3. **Environmental Data Considerations.** The site-specific environmental data is evaluated by using regional factors. The basic components are precipitation, drainage and elevation. [Exhibit 6.4-S](#) may be used to determine a site-specific environmental regional factor.

These factors should be adjusted for other conditions (e.g., seasonal traffic loads, subgrade frost heave potential, subgrade shrink/swell potential).

4. **Construction Material Strengths.** The different construction material strengths are evaluated by using a structural coefficient. The ranges of structural coefficients (SC) for material used on FLH projects are shown in [Exhibit 6.4-Z](#).



For other material types, typical Structural Coefficient (SC) values may be found in the AASHTO *Interim Guide* or may be estimated from Equation 6.4(1):

$$SC = 0.14 - 0.006(83 - R) \quad \text{(Metric) Equation 6.4(1)}$$

$$\text{(US Customary) Equation 6.4(1)}$$

where:

R = R-value determined at 2070 kPa (300 psi) exudation pressure (AASHTO T 190).

5. **Serviceability.** Generally, FLH roads should be designed for a terminal serviceability index of 2.0. However, roads with ADT's greater than 500 and/or roads considered primary routes may be designed using a terminal serviceability index of 2.5.

These elements are combined by using the design charts and procedures provided by [Exhibits 6.4-X](#) and [6.4-Y](#). Actual layer thickness is determined by using [Exhibit 6.4-Z](#) to satisfy the required structural number (SN).

For new construction, recommended minimum thicknesses of pavement structure materials are the following:

- asphaltic concrete pavement = 50 mm (2 in), and
- aggregate base course = 150 mm (6 in).

The information provided here should be considered a guideline and is subject to revisions and deviation based upon new developments and sound engineering judgment and analysis.

#### 6.4.4.2 Pavement Overlay Design

Four different design methods are used to design pavement overlays. These are the minimum thickness, engineering judgment, structural deficiency and deflection based methods. Generally, the method used on any given design problem will be dictated by the information available to the designer. If more than one design method is practical, the overlay should be checked by the other available methods. The following applies:

1. **Minimum Thickness.** Very thin pavement overlays tend to tear and separate from the underlying pavement during construction and are almost impossible to construct. If an overlay is not intended to serve any structural purpose, but only to correct a surface defect in the pavement, no further design is necessary and the overlay can be the minimum thickness. If, however, the overlay will serve a structural purpose, another design method must be used to determine thickness requirements.

A 50-mm (2-in) lift of asphaltic concrete pavement is normally the minimum depth of overlay for structural improvement. Overlays less than 50 mm (2 in) but no less than 20 mm (0.75 in) may be used under the following conditions:

- additional structural capacity is not required for the section proposed for resurfacing; and

- the primary function of the overlay is to improve the surface properties of the roadway (i.e., skid, noise and riding quality adversely affect operational safety characteristics).
2. **Engineering Judgment.** If a designer has extensive experience with pavements that are similar to the one being overlaid, it may be possible to arrive at the required design thickness by applying engineering judgment. While in the hands of an experienced engineer this method can yield good results, it is still little more than an educated guess. Therefore, using engineering judgment as the prime design method should be limited to those projects so small that it is uneconomical to gather the data for a more sophisticated approach. On the other hand, engineering judgment should always be used to check the reasonableness of the results of the more analytical methods.
  3. **Structural Deficiency.** The structural deficiency method consists of finding the structural number that would be required of a new pavement to support the design traffic and then subtracting the structural number of the existing pavement from it. The structural deficiency method can be summarized in these two equations:

$$SNO = SNN - SNE \quad \text{Equation 6.4(3)}$$

$$SNO = a_O D_O \quad \text{Equation 6.4(4)}$$

where:

$SN_O$	=	Structural number for the proposed overlay
$SN_N$	=	Structural number for a new pavement
$SN_E$	=	Structural number for the existing pavement
$a_O$	=	Layer coefficient for the overlay material
$D_O$	=	Overlay thickness, mm (in)

The structural number ( $SN_N$ ) required for a new pavement can be computed using the standard pavement design methods. Unfortunately, there is no single, clear-cut way to compute  $SN_E$ . There are several semi-empirical methods, but their use must be tempered with good judgment and, when possible, checked against one another. To a large extent, the accuracy of the structural deficiency method is dependent upon the accuracy of  $SN_E$ .

4. **Deflection and Mechanistic Based Method.** This method uses dynamic deflection measurements to estimate the condition of the existing pavement and the thickness of the required overlay. The first step in the design process is to take deflection measurements periodically along the roadways to be overlaid. Generally, a measurement is taken every 150 m (500 ft) along the roadway in each traveled lane. The measurements in adjacent lanes should be staggered by 75 m (250 ft) so that the maximum roadway coverage can be achieved.

These are only guidelines, however, and can be varied if there is reason to believe that the existing pavement is more or less variable than usual.

DARWIN provides an overlay design methods based upon deflection analysis and back calculation. Other mechanistic based design and back calculation programs are also available. The thickness of the full depth asphalt needed to sustain the design traffic is

found by processing the deflection data through the computer program. The required overlay thickness can then be computed from the following formula:

$$T_O = T_D - T_E \quad \text{Equation 6.4(5)}$$

where:

$T_O$  = Overlay thickness

$T_D$  = Design thickness for new pavement

$T_E$  = Equivalent existing pavement thickness

#### 6.4.4.3 Pavement Rehabilitation Design Other Than Overlay

The following are some of the major rehabilitation methods used as non-overlay techniques:

- full-depth repair,
- partial-depth patching,
- crack sealing,
- subsealing,
- milling,
- wedge and leveling,
- subdrainage,
- surface treatments, and
- recycling.

Descriptions of these methods can be found in the AASHTO *Guide for Design of Pavement Structures* 1993, FHWA [Pavement Rehabilitation Manual](#) and numerous Asphalt Institute publications dealing with specific techniques. [Exhibits 6.4-T](#), [6.4-U](#) and [6.4-V](#) may be used to collect and document pavement distress.

#### 6.4.5 MATERIAL SOURCES

The analysis of potential material sources often presents unusual and site-specific problems that require coordination with environmental planning sections as well as the project designer. Detailed investigations are sometimes limited by access and/or lack of detailed site information. A concentrated effort should be made to fully investigate and analyze each material source. Excavation with backhoe and/or core (auger) borings should outline boundaries of the proposed source and should extend at least 3 m (10 ft) beyond the expected floor elevation of the source. The remainder of the source should then be proven out by additional borings and/or excavations.

The total quantity of materials available from all material sources provided for a specific project should be approximately 25 percent in excess of the project needs. A material source investigation should provide the following minimum information:

- expected quality of processed materials and procedures necessary to obtain that quality;
- the boundary limits of proven materials and limits of previously used areas;
- specific areas and elevation of nonusable materials;
- previous uses of material from the source;
- recommendations on uses and limitations for processed materials; and
- listing of potential development, processing and handling problems that may occur during construction.

The following provides the basic procedural steps, initial source of reference material and standard forms for a typical material source investigation. Commercial sources do not normally require an investigation.

1. **Initiate Project.** The following applies:

- Identify available preliminary information (see [Exhibit 6.3-A](#)).
- Review local permit requirements.
- Identify environmental restrictions

2. **Review Available Geotechnical Data.** The following applies:

- Review previous material source geotechnical reports in vicinity of proposed project.
- Review published information (see [Exhibit 6.3-D](#)) with emphasis on geological surveys.
- Identify locations of existing sources in the vicinity.
- Obtain survey contour map and/or site specific cross sections.

3. **Plan Field Investigation.** The following applies:

- Determine drilling requirements (see [Exhibit 6.3-F](#)).
- Review checklists for site investigations ([Exhibit 6.4-A](#)) and material source investigation ([Exhibit 6.4-AA](#)) to identify information to be collected.
- Determine preliminary equipment requirements (see [Exhibits 6.3-C](#), [6.3-E](#) and [6.3-N](#)).
- Determine site restrictions and revise equipment requirements. A site visit may be required.
- Develop a Preliminary Boring and Testing Plan (see [Exhibit 6.3-I](#))

4. **Plan Sampling and Testing.** The following applies:
  - Determine sampling and testing requirements (see [Exhibits 6.3-F](#), [6.3-H](#) and [6.3-W](#)).
  - Record field information ([Exhibits 6.3-J](#), [6.4-C](#), [6.4-D](#), [6.4-H](#), [6.4-A](#) and [6.4-N](#) through [6.4-V](#), as applicable).
5. **Summarize Field Data.** The following applies:
  - Summarize soils and boring data, as appropriate ([Exhibit 6.4-H](#)).
6. **Perform analysis and write report.** The following applies:
  - Review the Material Source Investigation Checklist ([Exhibit 6.4-AA](#)) to ensure all appropriate information is available.
  - Write draft report (see [Section 6.6](#)).
  - Refer to the General Report Checklist ([Exhibit 6.4-I](#)) and the Site Investigation Checklist ([Exhibit 6.4-A](#)) to ensure appropriate report content.
  - Finalize report.

#### 6.4.6 LANDSLIDE ANALYSIS

Landslide analysis is perhaps one of the more difficult types of geotechnical analyses due to the variable size and complexity of landslides. TRB's *Landslide Investigation & Mitigation* provides a basis for analysis techniques and requirements. It is essential that survey information extend beyond the landslide limits to provide detailed analysis. For most Federal Lands Highway projects, the total size of the landslide and costs of correction must be subjectively evaluated in relationship to potential costs of noncorrection before detailed investigations are authorized and initiated.

The factor of safety for landslide analysis should vary with the type of facility, potential damages, amount and quality of soil strength data and size of the landslide. In addition, the reliability of site-specific rainfall and ground water level should be considered. Generally, a factor of safety in the 1.25 to 2.0 range is used, with 1.3 being most common. Use of low-cost methods (e.g., alignment shifts, grade changes, horizontal drains, rock buttresses and excavation) to remove driving forces should be routinely considered.

Information required from landslide analysis should include the following:

- physical limits and dimensions of the landslide,
- listing of probable causes for landslide,
- magnitude and rate of existing movements, and
- recommendations for corrective actions and evaluation of future risk.

The following provides the basic procedural steps, initial source of reference material and standard forms for a typical landslide investigation:

1. **Initiate Project.** The following applies:
  - Identify available preliminary information (see [Exhibit 6.3-A](#)).
  - Identify project related restrictions (e.g., financial, aesthetic, environmental).
2. **Review Available Geotechnical Data.** The following applies:
  - Review all previous geotechnical reports and information for specific project.
  - Review published information (see [Exhibit 6.3-D](#)).
  - Identify landslide problem history of the general area, and determine site specific history.
  - Obtain survey information (e.g., contour maps, cross sections and plans).
3. **Plan Field Investigations.** The following applies:
  - Determine drilling requirements (see [Exhibit 6.3-F](#)).
  - Review checklists for landslide correction ([Exhibit 6.4-BB](#)) to identify needed information to be collected.
  - Determine preliminary equipment requirements (see [Exhibits 6.3-C](#), [6.3-E](#), [6.3-G](#) and [6.3-N](#)).
  - Identify site access restrictions, and revise equipment requirements accordingly. A site visit may be necessary.
  - Develop a Preliminary Boring and Testing Plan (see [Exhibit 6.3-I](#)).
4. **Plan and Sampling Testing.** The following applies:
  - Determine sampling and testing requirements (see [Exhibits 6.3-F](#), [6.3-H](#) and [6.3-W](#)).
  - Appraise the need for in-situ testing and long-term monitoring devices.
  - Record field information ([Exhibits 6.3-J](#), [6.4-C](#), [6.4-D](#), [6.4-H](#), [6.4-A](#) and [6.4-N](#) through [6.4-V](#), as applicable).
5. **Summarize Field Data.** Summarize soil profile information (see [Exhibits 6.4-G](#) and [6.4-H](#)).
6. **Perform Analysis and Write Report.** The following applies:
  - Review the Landslide Correction Checklist ([Exhibit 6.4-BB](#)) to ensure all appropriate information is available.

- Perform appropriate analysis.
- Write draft report (see [Section 6.6](#)).
- Refer to the General Report Checklist ([Exhibit 6.4-I](#)) and the Site Investigation Checklist ([Exhibit 6.4-A](#)) to ensure appropriate report content.
- Finalize report.

#### 6.4.7 SUBSURFACE DRAINAGE

The presence of saturated soils or shallow ground water may produce adverse effects on the construction and maintenance of roadways and embankments. The sources of this subsurface water may be free water penetrating the subsurface due to the force of gravity, capillary water that moves upward through the underlying soil strata as a result of capillary action, or water vapor moving upward through the subgrade soil strata as a result of thermal gradients. In general, these adverse effects of excessive subsurface water cause slope failures including the sloughing and sliding of cut and fill slopes and unsatisfactory pavement performance as manifested in premature rutting, cracking, faulting, increasing roughness and a relatively rapid decrease in the level of serviceability.

This damage may be caused in various ways, including the following:

1. **Weakening.** When a roadbed is wholly or partly saturated, the application of dynamic loadings causes increased pore pressures and these reduce the internal friction and lower resistance to shearing action.
2. **Buoyancy.** The buoyant effect of the water reduces the weight of the particles and correspondingly lowers the friction between them.
3. **Expansion.** The volume of some soils is greatly increased by added water, causing differential heaving and weakening of the pavement structure.
4. **Frost Heave.** Freeze-thaw activity related to water in or under a pavement structure is the most common cause of volume changes leading to pavement break-up and potholes.

Prevention of subsurface water problems in highway engineering may be accomplished by either selective highway location, replacement of poor soils and the use of select, free draining, granular subbase materials or by using subsurface drainage systems. This Section will only discuss design guidance for subsurface drainage systems. The functions of subsurface drainage are to reduce the previously mentioned adverse effects on roadways. These functions are more specifically stated in terms of the following requirements:

- to draw-down or lower a highway water table in the area of a highway, parking lot or other type of transportation improvement project;
- to eliminate active springs or seeps beneath the pavement by intercepting the seepage above an impervious boundary;

- to drain surface water infiltrating into the structural section by the following:
  - + through a pervious pavement;
  - + through cracks, joints or other breaks in the continuity of the pavement and shoulder surfaces;
  - + from an improperly-drained median area; or
  - + from side ditches; and
- to collect discharge from other drainage systems.

In order to design a reliable, economic and adequate subsurface drain, it is desirable to collect the following information:

- determine, during the preliminary soil survey, the location of all seepage areas that may cause water to enter the structural elements of the pavement;
- determine the maximum rate of flow of water that may enter the structural section from any seepage and infiltration;
- find the location of a source of aggregate suitable for filter material to prevent clogging of drains by water-borne soil or determine the suitability of using a filter fabric;
- determine source of aggregate which, if needed, may be used as drainage blanket to remove the water from beneath the pavement; and
- obtain and evaluate climatic data with respect to frost heaving.

The most common way of identifying subdrainage systems is in terms of their location and geometry. The most familiar classifications of subsurface drainage systems include underdrains, horizontal drains, drainage blankets and wells. The following applies:

1. **Underdrains.** These subsurface drains are categorized as longitudinal drains if they are located parallel to the roadway centerline (both in the horizontal and vertical alignment) and as transverse drains if they run beneath the roadway either at right angles to the roadway centerline or skewed in the so-called “herringbone” pattern. These drains are located not only at the edge of or under the pavement, but may also act as interceptor drains in wet cut slopes. Typically, these drains involve a trench of substantial depth, a collector pipe, free draining aggregate and a protective filter fabric of some kind.

The function of fabrics as filters is to allow removal of ground water without the build-up of excessive seepage forces or water pressures. The fabric must also prevent piping or subsurface erosion of the soil. In these applications, water flows across the filter into a water-conducting medium, which is usually a trench filled with a free draining aggregate and a slotted or perforated pipe that quickly removes the water. Geotechnical filter fabrics are manufactured from a number of different materials, including polypropylene, polyester, nylon, polyethylene and polyvinylidene chloride.



For details concerning specifications for various kinds of underdrain pipe, free draining aggregate and filter fabrics, refer to the references in [Section 6.2](#).

In lieu of pipe underdrains, the use of prefabricated drainage systems (geocomposite drains) for subsurface drainage is increasing rapidly. Variables that should be considered in the design of a geocomposite drain application are drain orientation, in-situ stress, temperature, hydraulic conditions, potential for clogging, permeability and chemical resistance.

Depending on the source of subsurface water and the function of the drain, less sophisticated underdrains may be used. These may include “french drains,” consisting of a shallow trench filled with open graded aggregate or a deep trench drain with filter fabric enveloping an open graded aggregate. [Exhibits 6.4-CC through 6.4-GG](#) show various underdrain details. These drains perform the basic requirement of carrying off all water entering the system by using a protective filter medium to prevent clogging of the drain.

2. **Horizontal Drains.** This drainage system consists of horizontal pipes drilled into cut slopes or fill slopes to tap springs and relieve porewater pressures. The skew and inclination of horizontal pipes must be determined on a project-by-project basis, and may have to be adjusted in the field as groundwater is encountered. In ordinary installation, the ends of the perforated, small diameter drain pipes are simply left projecting from the slope and the flow is picked up in drainage ditches.

In more elaborate installations, however, drainage galleries or tunnels may be required to carry the large flows, and some type of pipe collector system may be used to dispose of the water outside of the roadway limits. The following describes two types of horizontal drains:

- a. *Drainage Blankets.* Drainage blankets are applied as a very permeable layer, the length (in the direction of flow) and width of which are large relative to its thickness. Drainage blankets used in conjunction with a longitudinal drain can help to improve the surface stability and, thus, relieve sloughing of cut slopes by preventing the development of a seepage surface. Horizontal drainage blankets can be used beneath or as an integral part of the pavement structure to remove water from infiltration or to remove ground water from both gravity and artisan sources.

Although relatively pervious granular materials are often used for base and subbase courses, these layers will not function as drainage blankets unless they are specifically designed and constructed to do so. This requires an adequate thickness of material with a very high coefficient of permeability, a positive outlet for the water collected, and in some instances the use of one or more protective filter layers.

- b. *Wells.* Wells can be used to control the flow of ground water and relieve pore water pressures in potentially unstable highway slopes. Wells are sometimes used in conjunction with another drainage system to penetrate an impervious layer that prevents or hinders the necessary percolation of subsurface water.

Site Investigation Checklist			
<b>Project:</b> _____ <b>Location:</b> _____ <b>Prepared by:</b> _____ <b>Date:</b> _____			
Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Is a plan profile (subsurface cross section) of the investigation site provided and clearly identified?			
2. Are the locations of all samples, boring, test pits, probes, geophysical, and field testing shown on a plan view?			
3. Are the locations of the proposed geotechnical features, existing structures, utilities, and other physical site features shown on a plan view?			
4. Are test hole numbers and dates included for each boring or exploration.			
5. Do the profile boring logs contain a word description and/or graphic depiction of soil and rock types?			
6. Is sample type and depth at which each sample was taken noted on the boring logs?			
7. Are SPT blow counts provided on the boring logs?			
8. Are groundwater levels and date measured shown on the boring logs?			
9. Are percent rock core recovery and RQD values shown on the boring logs?			
10. If cone penetrometer probes are made, are logs of cone probes shown, including plots of cone resistance and friction ration with depth?			
11. Is location of other field tests performed at the boring site (such as vane shear, pressure-meter, drive casing, etc.) shown on the boring logs?			
12. Are soil classification tests determined on selected representative samples to verify field visual soil identifications?			
13. Are laboratory test results (natural moisture content, gradation, Atterberg limits, shear strength, consolidation, etc.) included and summarized?			

**Exhibit 6.4-A SAMPLE OF SITE INVESTIGATION CHECKLIST**

<b>Roadway Cut and Embankment Checklist</b>			
<b>Project:</b> _____			
<b>Location:</b> _____			
<b>Prepared by:</b> _____ <b>Date:</b> _____			
<b>Components</b>	<b>Check Appropriate Box</b>		
	<b>Yes</b>	<b>No</b>	<b>Not Applicable</b>
1. Are station to station descriptions included for:			
a. Existing surface and subsurface drainage?			
b. Evidence of springs and excessively wet areas?			
c. Slides or slumps noted along the alignment?			
2. Are station to station recommendations included for:			
a. Cut slope design?			
b. Are clay slopes designed for minimum FS = 1.50?			
c. Fill slope design?			
d. Will slope design provide minimum FS = 1.25?			
e. Usage of excavated soils?			
f. Estimated shrink-swell factors for excavated materials?			
g. Specific surface/subsurface drainage considerations?			
h. Identifying subexcavation limits of unsuitable soils?			
i. Erosion protection measures for backslopes, sideslopes, and ditches, including riprap or special slope treatments?			
j. Are special blasting specifications needed to insure stable rock slopes and minimize future rockfall?			
k. Need for special rock slope stabilization measures (e.g., rockfall catch ditch, wire mesh slope protection, shotcrete, rock bolts, etc.) identified?			
3. Are recommended contract specifications provided?			
<i>Note: Factor of Safety (FS)</i>			

**Exhibit 6.4-B SAMPLE OF ROADWAY CUT AND EMBANKMENT CHECKLIST**

1. Location, orientation, and number of planes are numeric. Data units are alphabetic and/or numeric. All other information is alphabetic.
2. Surface type, line type and rock type are three letter codes. Infilling water, form, roughness, and termination are one letter codes.
3. Record all codes and their full proper descriptions on a reference chart.
4. Record position within the data unit or traverse under location. Each data unit should include data from within one structural unit only.
5. Thickness, spacing, and length are entered according to the size notation given below.

Traverse	Data Unit					Northing					Easting					Elevation					Inclination				
(Data Unit)																									
Information	Bearing			Length			No. Points			Structural Unit			Formation			Declination			Observer						
Remarks																									

Size Notations		(A through I mm, J through S m)					
A	<0.26	E	12.5–25	J	0.3–0.6	O	9.0–18.0
B	0.25	F	25–50	K	0.6–1.2	P	18.0–30.0
C	0.25–6.5	G	50–100	L	1.2–2.4	Q	30.0–60.0
D	6.5–12.5	H	100–200	M	2.4–4.5	R	60.0–120.0
		I	200–300	N	4.5–9.0	S	>120.0

Surface type	Infilling	Water	Form	Roughness	Term
C – Contact	A – Clay	W – Wet	P –Planor	V – Very rough(JRC=25)	0 – neither end visible
F – Fault	F – Iron Metals	D – Dry	C –Curved	R – Rough(JRC=15)	1 – one end visible
S – Shear	W – Colcite	M – Moist	U –Undulating	S – Smooth(JRC=5)	2 – both ends visible
J – Joint	K – Chlorite		S –Stepped	P – Polished(JRC=0)	
B – Bedding	Q – Quartz		I –Irregular		
L – Schistosity or Foliation	P – Pyrite				
V – Vein					

[illegible]

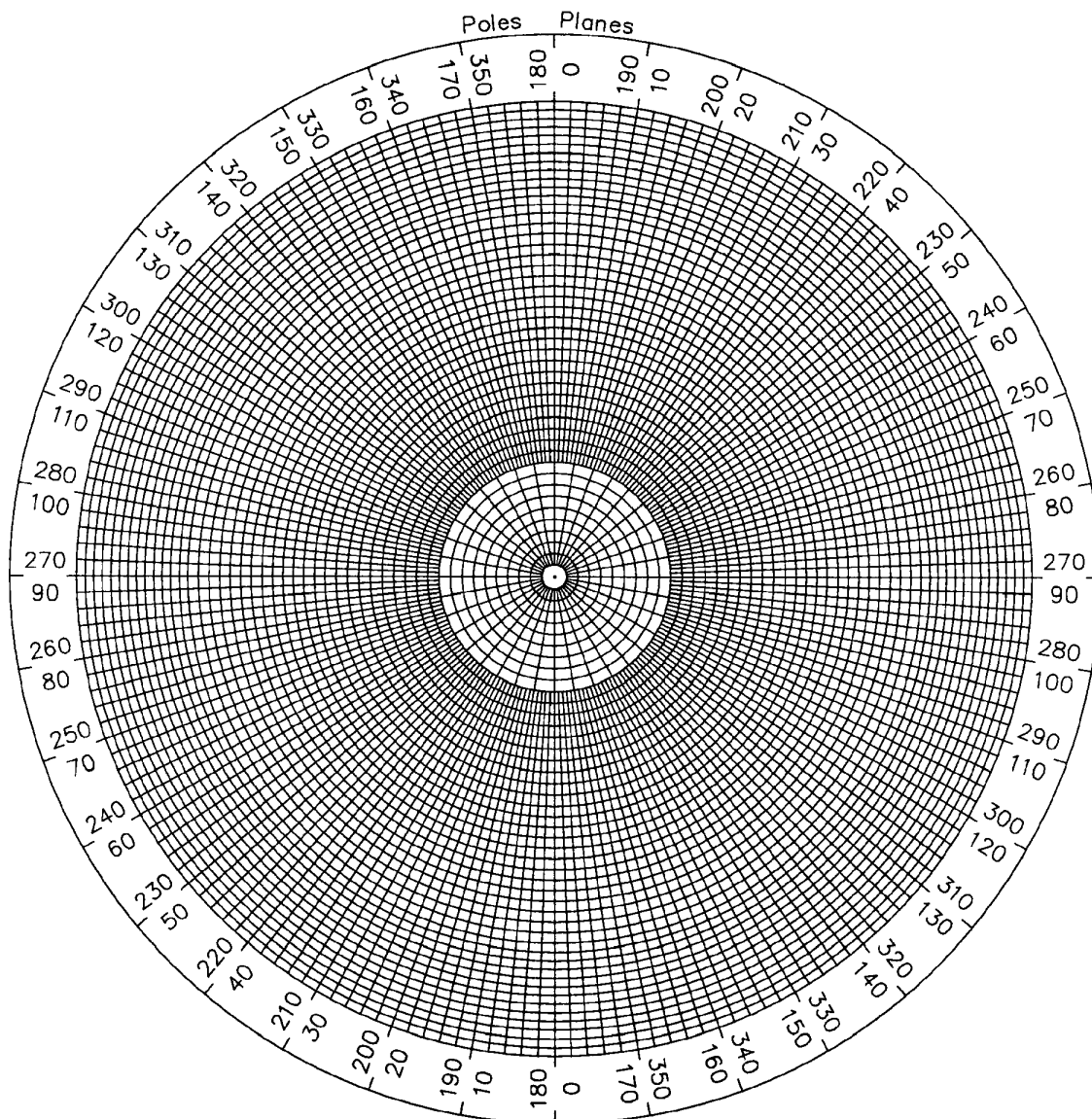
### Exhibit 6.4-C FIELD MAPPING – ROCK STRUCTURES\*

**Field Mapping – Rock Structures\* (continued)**

Project \_\_\_\_\_

Location \_\_\_\_\_

Plotted by: \_\_\_\_\_ Date: \_\_\_\_\_



Note: plot for data collected from field mapping of the rock structure.

**Figure 6.4-C FIELD MAPPING – ROCK STRUCTURES\***  
(Continued)

Beginning Reference Location: \_\_\_\_\_ Performed by: \_\_\_\_\_

Station to Station	Description of Soil or Rock	Recommended Slope Ratios	Shrink/Swell Factor	Water Problem Area (Yes/No)	Remarks

**Exhibit 6.4-D SAMPLE OF SUMMARY OF SOIL SURVEY**

<b>Summary of Water Problem Areas</b>		
Project: _____		
Beginning Reference Location: _____		
Performed By: _____ Date Performed: _____		
<b>From Station to Station</b>	<b>Description of Problem</b>	<b>Recommended Solution</b>

**Exhibit 6.4-E SUMMARY OF WATER PROBLEM AREAS**

Material	Measured				
	In-Situ	Loose		Embankment	
	Mass Density <sup>1</sup> kg/m <sup>3</sup>	Mass Density <sup>2</sup> kg/m <sup>3</sup>	% Swell <sup>3</sup>	Mass Density <sup>2</sup> kg/m <sup>3</sup>	% Swell/Shrink <sup>3</sup>
Andesite	2930	1760	67	2050	43
Basalt	2935	1790	64	2160	36
Bentonite	1600	1185	35	—	—
Breccia	2400	1800	33	1890	27
Calcite-Calcium	2670	1600	67		
Caliche	1440	1245	16	1900	-25
Chalk	2410	1285	50	1810	33
Charcoal	—	610	—	—	—
Cinders	760	570	33	840	-10
Clay					
Dry	1910	1275	50	2120	-10
Damp	1985	1180	67	2205	-10
Conglomerate	2205	1660	33		
Decomposed rock					
75% R. 25% E.	2445	1865	31	2185	12
50% R. 50% E.	2225	1610	38	2375	-6
25% R. 75% E.	2005	1405	43	2205	-9
Diorite	3095	1855	67	2165	43
Diotomaceous earth	870	540	62		
Dolomite	2890	1725	67	2015	43
Earth, loam					
Dry	1795	1230	50	2090	-12
Damp	2000	1400	43	2090	-4
Wet, mud	1745	1745	0	2090	-20
Gabbro	2615	1565	67	1825	43
Feldspar	3095	1855	67	2165	43
Gneiss	2700	1615	67	1885	43
Gravel					
Dry—					
Uniformly Graded	1770	1600	10	1870	-5
Average Gradation	1945	1620	20	2120	-8
Well Graded	2180	1645	33	2450	-11
Wet—					
Uniformly Graded	1965	1870	5	1870	-5
Average Gradation	2160	1950	10	2120	-2
Well Graded	2425	2090	16	2450	-1
Granite	2695	1565	72	1880	43
Gumbo					
Dry	1915	1275	50	2120	-10
Wet	1985	1200	67	2205	-10
Gypsum	2420	1410	72		
Igneous rocks	2795	1675	67	1960	43

**Exhibit 6.4-F SHRINK/SWELL FACTORS FOR COMMON MATERIALS\***  
(Metric)



Material	Measured				
	In-	Loose		Embankment	
	Mass Density <sup>1+</sup> kg/m <sup>3</sup>	Mass Density <sup>2</sup> kg/m <sup>3</sup>	% Swell <sup>3</sup>	Mass Density <sup>2</sup> kg/m <sup>3</sup>	% Swell/Shrink <sup>3</sup>
Kaolinite					
Dry	1915	1275	50		
Wet	1985	1190	67		
Limestone	2600	1595	63	1910	36
Loess					
Dry	1910	1275	50	2120	-10
Wet	1985	1190	67	2205	-10
Marble	2680	1600	67	1875	43
Marl	2220	1330	67	1555	43
Masonry, rubble	2325	1395	67	1630	43
Mica	2885	1725	67		
Pavement					
Asphalt	1920	1150	50	1920	0
Brick	2400	1440	67	1685	43
Concrete	2350	1405	67	1645	43
Macadam	1685	1010	67	1685	0
Peat	700	530	33		
Pumice	640	385	67		
Quartz	2585	1550	67	1780	43
Quartzite	2680	1610	67	1875	43
Rhyolite	2400	1435	67	1700	43
Riprap rock	2670	1550	72	1870	43
Sand					
Dry	1710	1535	11	1920	-11
Wet	1915	1835	5	2050	-11
Sandstone	2415	1495	61	1795	34
Schist	2685	1610	67	1880	43
Shale	2640	1470	79	1775	49
Shale	1920	1410	36	2310	-17
Siltstone	2415	1495	61	2705	-11
Slate	2670	1540	77	1870	43
Talc	2750	1650	67	1930	43
Topsoil	1440	960	56	1945	-26
Tuff	2400	1600	50	1810	33

Notes:

1. Subject to average  $\pm 5\%$  variation.
2. Mass densities are subject to adjustments in accordance with modified swell and shrinkage factors.
3. Based on average in-situ densities. A negative number represents a shrinkage. Factors subject to  $\pm 33\%$  variation.

**Exhibit 6.4-F SHRINK/SWELL FACTORS FOR COMMON MATERIALS**  
**(Metric)**  
 (Continued)

Material	Measured				
	In-Situ	Loose		Embankment	
	Mass Density <sup>1</sup> lb/ft <sup>3</sup>	Mass Density <sup>2</sup> lb/ft <sup>3</sup>	% Swell <sup>3</sup>	Mass Density <sup>2</sup> lb/ft <sup>3</sup>	% Swell/Shrink <sup>3</sup>
Andesite			67		43
Basalt			64		36
Bentonite			35		—
Breccia			33		27
Calcite-Calcium			67		
Caliche			16		-25
Chalk			50		33
Charcoal			—		—
Cinders			33		-10
Clay					
Dry			50		-10
Damp			67		-10
Conglomerate			33		
Decomposed rock					
75% R. 25% E.			31		12
50% R. 50% E.			38		-6
25% R. 75% E.			43		-9
Diorite			67		43
Diatomaceous earth			62		
Dolomite			67		43
Earth, loam					
Dry			50		-12
Damp			43		-4
Wet, mud			0		-20
Gabbro			67		43
Feldspar			67		43
Gneiss			67		43
Gravel					
Dry—					
Uniformly Graded			10		-5
Average Gradation			20		-8
Well Graded			33		-11
Wet—					
Uniformly Graded			5		-5
Average Gradation			10		-2
Well Graded			16		-1
Granite			72		43
Gumbo					
Dry			50		-10
Wet			67		-10
Gypsum			72		
Igneous rocks			67		43

**Exhibit 6.4-F SHRINK/SWELL FACTORS FOR COMMON MATERIALS**  
**(US Customary)**  
 (Continued)

Material	Measured				
	In-	Loose		Embankment	
	Mass Density <sup>1+</sup> lb/ft <sup>3</sup>	Mass Density <sup>2</sup> lb/ft <sup>3</sup>	% Swell <sup>3</sup>	Mass Density <sup>2</sup> lb/ft <sup>3</sup>	% Swell/Shrink <sup>3</sup>
Kaolinite					
Dry			50		
Wet			67		
Limestone			63		36
Loess					
Dry			50		-10
Wet			67		-10
Marble			67		43
Marl			67		43
Masonry, rubble			67		43
Mica			67		
Pavement					
Asphalt			50		0
Brick			67		43
Concrete			67		43
Macadam			67		0
Peat			33		
Pumice			67		
Quartz			67		43
Quartzite			67		43
Rhyolite			67		43
Riprap rock			72		43
Sand					
Dry			11		-11
Wet			5		-11
Sandstone			61		34
Schist			67		43
Shale			79		49
Shale			36		-17
Siltstone			61		-11
Slate			77		43
Talc			67		43
Topsoil			56		-26
Tuff			50		33

**Notes:**

1. Subject to average  $\pm 5\%$  variation.
2. Mass densities are subject to adjustments in accordance with modified swell and shrinkage factors.
3. Based on average in-situ densities. A negative number represents a shrinkage. Factors subject to  $\pm 33\%$  variation.

**Exhibit 6.4-F SHRINK/SWELL FACTORS FOR COMMON MATERIALS**  
**(US Customary)**  
 (Continued)

**Interpreted Design Soil Profile**

Material Number	Description	Soil Parameters		
		C	$\phi$	$Y_T$

**Exhibit 6.4-G SAMPLE OF INTERPRETED DESIGN SOIL PROFILE**

**Exhibit 6.4-H SAMPLE OF SOILS AND FOUNDATION PLAN AND PROFILE SHEET**

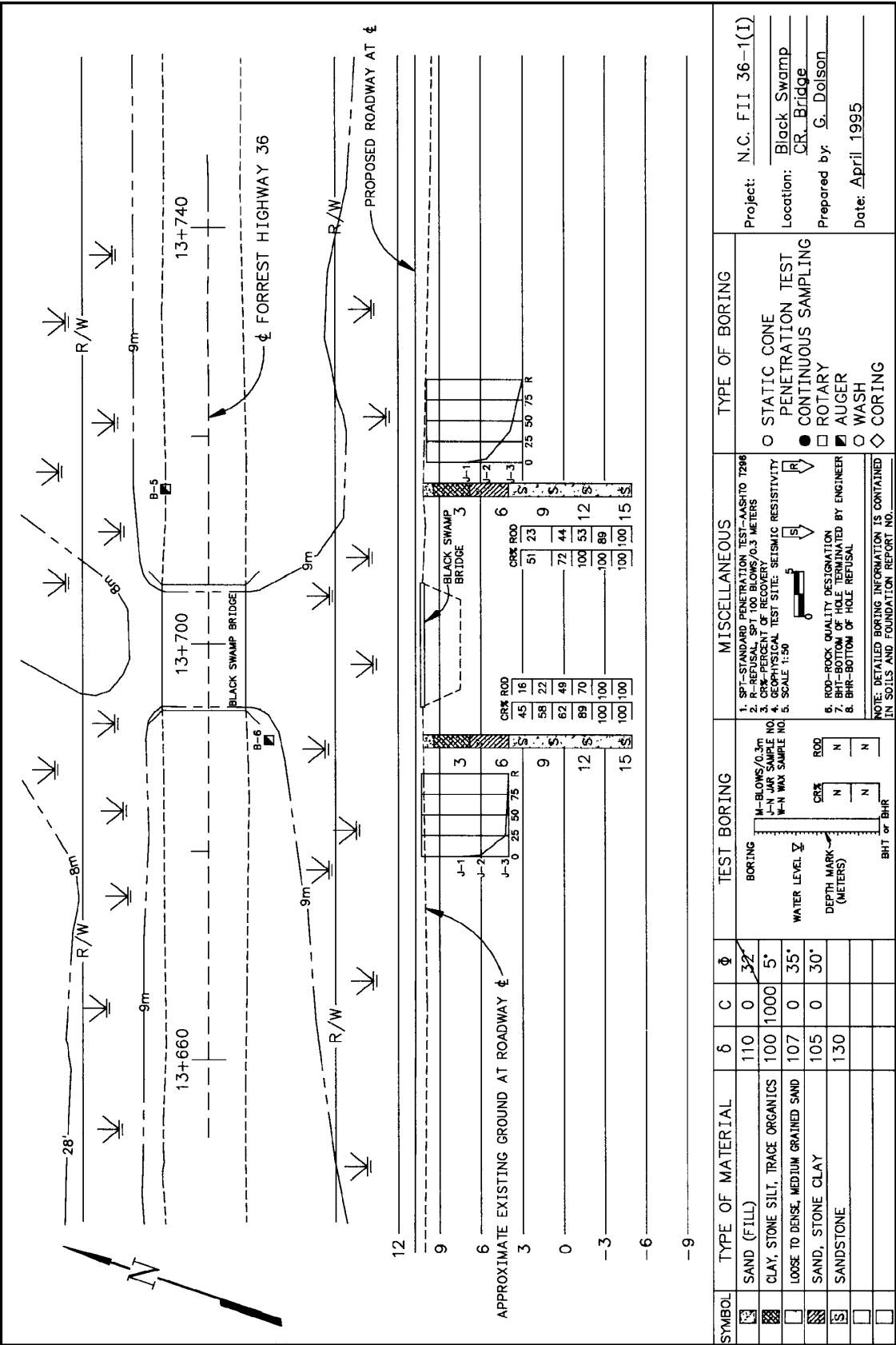


Exhibit 6.4-H SOILS AND FOUNDATION PLAN AND PROFILE SHEET  
(Continued)

**General Report Checklist****Project:** \_\_\_\_\_**Location:** \_\_\_\_\_**Prepared by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

	Check Appropriate Box		
	Yes	No	Not Applicable
<b>Components</b>			
1. Is a title page included?			
2. Is a vicinity map included?			
3. Is a standard report format followed? (i.e., introduction, results, discussion, recommendation, details and appendices)			
4. Is the scope and purpose of report and authority for investigation summarized in the introduction?			
5. Is the summary of field explorations and lab testing given in the results?			
6. Is the description of general subsurface soil, rock and groundwater conditions given in the results?			
7. Are concise descriptions given for geologic features and topography of the area in the discussion?			
8. Are recommendations concise and in sufficient detail to design the project or serve the intended purpose?			
9. Is the following information included with the geotechnical report? (Typically included in report appendices):			
•Test hole logs?			
•Laboratory test data?			
•Field test data?			
•Photographs?			

**Comments** \_\_\_\_\_

\_\_\_\_\_

**Exhibit 6.4-I SAMPLE OF GENERAL REPORT CHECKLIST**

Identifying Characteristic	Potential Problem/Condition					
	Soil/Rock Interface	Variability of Pavement	Settlement	Frost Heave	Poor Drainage	Slope Instability
<b>In-Situ Properties</b>						
Soil Classification	X	X	X	X	X	X
Plasticity			X	X	X	X
Natural Moisture	X	X	X		X	X
Subgrade Strength		X		X		
<b>Existing Conditions</b>						
Standing/Seeping Water	X	X	X	X	X	X
Subgrade Support		X		X	X	
Pavement Thickness		X		X	X	
Slope Ratio	X				X	X
Pavement Distress		X	X	X	X	X

**Exhibit 6.4-J ROADWAY SOILS ANALYSIS FACTORS**



Foundation Type	Use	Applicable Soil Conditions
Spread Footing	Individual columns, walls, bridge piers.	Any conditions where bearing capacity is adequate for applied load and abutments are not susceptible to scour or footings placed below the anticipated scour depth. May use on single stratum; firm layer over soft layer or soft layer over firm layer. Check immediate, differential, and consolidation settlements.
Mat Foundation	Same as spread and wall footings. Very heavy column loads. Usually reduces differential settlements and total settlements.	Generally soil bearing value is less than for spread footings; over one-half area of structure covered by individual footings. Check settlements.
Friction Piles	In groups to carry heavy column loads wall loads, bridge pier and abutment loads. Requires pile cap.	Scour susceptible foundation conditions. Low strength surface and near surface soils. Load distributed along pile shaft. Check for potential pile settlement. Corrosive soils may require use of timber or concrete pile material.
End Bearing Piles	In groups (at least 2) to carry heavy column loads, wall loads, bridge pier and abutment loads. Requires pile cap.	Scour susceptible foundation conditions. Low strength surface and near surface soils. End of pile located on firm strata.
Drilled Shafts (Friction and End Bearing)	Larger column loads than for piles but eliminates pile cap by using caissons as column extension.	Scour susceptible foundation conditions. Low strength surface and near surface soils. Load distributed along shaft (friction) or end of shaft bearing on firm strata (end bearing).
Sheetpile	Temporary retaining structures for excavations, waterfront structures, cofferdams. Permanent abutment walls.	Any low to medium dense soil free of boulders. Waterfront structures may require special or corrosion protection. Cofferdams require control of fill material.

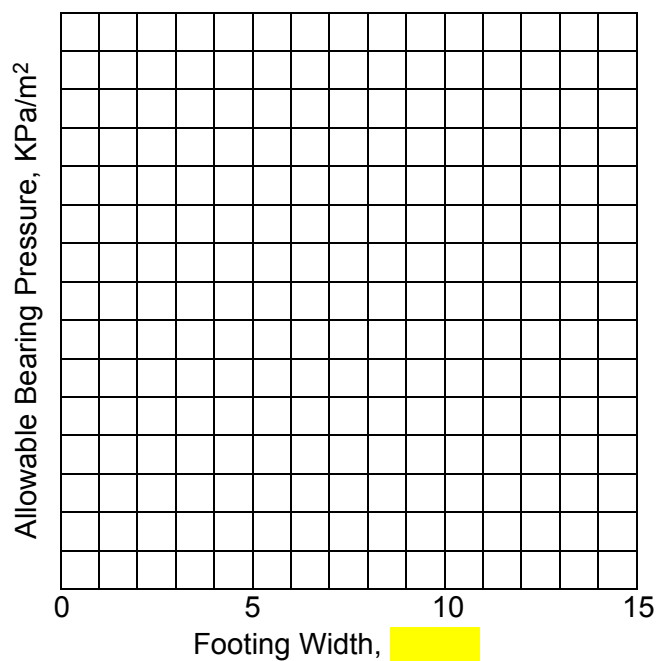
#### Exhibit 6.4-K PRELIMINARY FOUNDATION TYPE SELECTION

### Allowable Bearing Pressure for Spread Footings

Project: \_\_\_\_\_

Footing Location: \_\_\_\_\_

Designer: \_\_\_\_\_ Date: \_\_\_\_\_



Design Criteria:

1. Soil Type: \_\_\_\_\_
2. Factor of Safety: \_\_\_\_\_
3. Minimum Soil Above Footing Elevation: \_\_\_\_\_
4. Minimum Depth to Water Table: \_\_\_\_\_
5. Settlement at Bearing Pressure: \_\_\_\_\_
6. Maximum Total Settlement: \_\_\_\_\_

**Exhibit 6.4-L ALLOWABLE BEARING PRESSURE FOR SPREAD FOOTINGS  
(Metric)**

*To Be Provided*

**Exhibit 6.4-L ALLOWABLE BEARING PRESSURE FOR SPREAD FOOTINGS  
(US Customary)**

Allowable Pile Capacity, kN											
Depth of Penetration, Meters											
	<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> Project: _____  Location: _____  Substructure Unit: _____ </div> <div style="width: 45%;"> Factor of Safety: _____ </div> </div>										

**Exhibit 6.4-M ALLOWABLE PILE CAPACITY CURVE  
(Metric)**

*To Be Provided*

**Exhibit 6.4-M ALLOWABLE PILE CAPACITY CURVE  
(US Customary)**

<b>Spread Footings Checklist</b>			
<b>Project:</b> _____			
<b>Location:</b> _____			
<b>Prepared by:</b> _____ <b>Date:</b> _____			
Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Are spread footings recommended for foundation support or provided as an alternative to deep foundations?			
2. Are recommended bottom of footing elevations and reasons for recommendations (e.g., based on frost depth, estimated scour depth or depth to competent bearing material) given?			
3. Are the recommended allowable soil or rock bearing pressures given?			
4. Are estimated footing settlements given?			
5. Where spread footings are recommended to support abutments placed in the bridge end fills, are gradation and compaction requirements provided for select end fill and backwall drainage material?			
6. Have the following important construction considerations been adequately addressed?			
a. Materials on which the footing is to be placed — method by which project inspector can verify that material is as expected?			
b. Excavation requirements — safe slopes for open excavations, need for sheeting or shoring?			
c. Fluctuation of groundwater table?			
7. Are necessary contract special provisions provided?			
Comments _____ _____			

**Exhibit 6.4-N SAMPLE OF SPREAD FOOTING CHECKLIST**

Piles Checklist			
Project: _____			
Location: _____			
Prepared by: _____ Date: _____			
Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Are most suitable pile types (displacement, nondisplacement, pipe pile, concrete pile, H-pile, etc.) analyzed?			
2. Are reasons given for choice and/or exclusion of certain pile types?			
3. Are estimated pile lengths and estimated tip elevations given?			
4. Are recommended allowable pile design loads given?			
5. Has pile group settlement been estimated? (only of practical significance for friction pile groups in cohesive soils or large heavy structures on friction pile groups in sand)			
6. If a specified or minimum pile tip elevation is recommended, is the reason given for the required tip elevation? (e.g., underlying soft layers, scour, downdrag, piles uneconomically long, etc.)			
7. Has design analysis verified that the recommend pile type can be driven to the estimated or specified tip elevation without damage? (especially applicable where dense gravel-cobble-boulder layers or other obstructions have to be penetrated)			
8. Where the bridge abutment is to be supported on end-bearing piles and significant long-term settlement of the subsoil will occur (e.g., for embankments built over clays or soils with high organic content):			
a. Has abutment downdrag load been estimated and considered in design?			
b. Has bridge approach slab been considered to moderate differential settlement between bridge ends and fill?			
9. If the majority of subsoil settlement will not be removed prior to abutment construction, has estimate been made of the amount of abutment rotation that can occur due to lateral squeeze of soft subsoil?			

Exhibit 6.4-O SAMPLE OF PILES CHECKLIST

<b>Piles Checklist</b>			
<b>Project:</b> _____			
<b>Location:</b> _____			
<b>Prepared by:</b> _____ <b>Date:</b> _____			
<b>Components</b>	<b>Check Appropriate Box</b>		
	<b>Yes</b>	<b>No</b>	<b>Not Applicable</b>
10. Has horizontal abutment movement been considered?			
11. Has pile load test program or dynamic testing been considered?			
12. For a structure in high seismic risk area, has assessment been made of liquefaction potential of foundation soil during design earthquake? (Note only loose saturated sands and silts are "susceptible" to liquefaction)			
13. Construction considerations - have the following important construction considerations been adequately addressed?			
a. Pile driving details and what may be encountered during driving such as boulders or other obstructions (any need for pre-augering, jetting, spudding, pile tip reinforcement, driving shoes, etc.?)			
b. Excavation and the need for sheeting or shoring? (Safe slopes for open excavating)			
c. Fluctuations in groundwater table?			
d. Have effects of pile driving operation on adjacent structures been evaluated (e.g., protection against damage caused by footing excavations or pile driving vibrations)?			
e. Should preconstruction condition survey be made on adjacent structures (to document for possible construction damage claims)?			
<u>Comments</u> _____ _____ _____ _____			

**Exhibit 6.4-O PILES CHECKLIST**  
(Continued)



<b>Drilled Shaft Checklist</b>			
<b>Project:</b> _____ <b>Location:</b> _____ <b>Prepared by:</b> _____ <b>Date:</b> _____			
<b>Components</b>	<b>Check Appropriate Box</b>		
	<b>Yes</b>	<b>No</b>	<b>Not Applicable</b>
1. Recommended shaft diameter(s) and length?			
2. Allowable design load given for various diameter shafts recommended?			
3. Allowable end bearing value given?			
4. Allowable side friction value given?			
5. Settlement estimated for recommended design load?			
6. Where lateral load capacity of shaft is an important design consideration, are P-Y (load versus deflection) curves or soils data provided in geotechnical report which will allow structural engineer to evaluate lateral load capacity of shaft?			
7. Is static load test (to plunging failure) recommended?			
8. Construction considerations?			
a. Have construction methods been evaluated? (i.e., can dry method or slurry method be used or will casing be required)			
b. If casing will be required, can casing be pulled as shaft is concreted? (this can result in significant cost savings on very large diameter shafts)			
c. If artesian water may be encountered in the shaft excavation, have provisions been included? (such as by requiring casing and tremie seal)			
9. Are boulders likely to be encountered? (Note - if boulders are likely to be encountered, then the use of shafts should be questioned due to serious construction installation difficulties and possible higher costs.)			
10. Are recommended contract special provisions provided?			
<u>Comments</u> _____ _____			

**Exhibit 6.4-P SAMPLE OF DRILLED SHAFT CHECKLIST**

Retaining Wall Checklist			
Project: _____			
Location: _____			
Prepared by: _____ Date: _____			
Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Does the geotechnical report include recommended soil strength parameters and groundwater elevation for us in computing wall design lateral earth pressures and factor of safety for overturning, sliding and external slope stability?			
2. Does the design lateral earth pressure include the effects of soil backfill strength, slope geometry and surcharge loads?			
3. Has the most suitable and cost-effective wall type(s) been selected for the specific site conditions?			
4. Are reasons given for the choice and/or exclusion of certain wall types (gravity, reinforced soil, tieback, cantilever, bin, gabion, etc.)?			
5. Does wall design provide for and identify minimum acceptable factors of safety against overturning, sliding and external slope stability?			
6. If wall will be placed on compressible foundation soils, is estimated total settlement, differential settlement and time rate of settlement given?			
7. Can selected wall system(s) tolerate the estimated differential settlement?			
8. If special drainage details are needed behind and/or beneath the wall, are recommended details provided in the geotechnical report?			
9. Is proposed to bid alternative wall designs?			
10. Construction considerations:			
a. Are excavating requirements covered (safe slopes for open excavations, need for sheeting or shoring, etc.)?			
b. Fluctuation of groundwater table?			
11. Are recommended contract special provisions provided?			

Exhibit 6.4-Q SAMPLE OF RETAINING WALL CHECKLIST

Pavement Design Checklist			
Project: _____			
Location: _____			
Prepared by: _____ Date: _____			
Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Has a visual distress assessment of the existing pavement been made and is summary of results provided?			
2. Has the roughness of the existing pavement surface been measured and are results summarized?			
3. Have deflection tests been made on the existing pavement and the results summarized?			
4. Has a subsection breakdown been provided to group similar existing conditions, pavement structure and expected traffic loads within the project?			
5. Are traffic estimates provided that include total ADT, trucks, and accumulative equivalent 80KN (18,000 lbs)?			
6. Are strength properties and thickness of each of the pavement layers and subsections included?			
7. Is the design method used to develop the pavement alternatives identified and are all inputs used for design clearly summarized?			
8. Are advantages and disadvantages of each alternative provided for the acceptable pavement structures?			
9. Are reasons for recommended pavement structure alternatives clearly stated?			
10. Are construction problems, weather restrictions, water and/or material problems considered?			
11. Are recommended contract specifications provided?			
12. Has a life cycle cost analysis been performed?			

Exhibit 6.4-R SAMPLE OF PAVEMENT DESIGN CHECKLIST

Precipitation		Elevation		Drainage	
Millimeters	Factor ( $P_f$ )	Meters	Factor ( $E_f$ )	Condition	Factor ( $D_f$ )
< 250	0	< 2000	0	Good	0
≥ 250 to <325	0.25	≥ 2000 to <2300	0.25	Fair	0.50
≥ 325 to < 425	0.50	≥ 2300 to <2600	0.50	Poor	1.0
≥ 425 to <600	1.0	≥ 2600 to <2900	1.0	Severe	2.0
≥ 600	1.5	>2900	1.5		

*Note: Total Regional Factors (RF) =  $P_f + E_f + D_f$*

#### **Exhibit 6.4-S REGIONAL FACTOR GUIDELINES FOR PAVEMENT**

[illegible]

**Exhibit 6.4-T PAVEMENT BORE LOG**

[illegible]

6-90

### Portland Cement Concrete Pavement Condition Survey\*

Project Name: \_\_\_\_\_

Beginning Reference Location: \_\_\_\_\_

Direction: \_\_\_\_\_ Logged by: \_\_\_\_\_ Date: \_\_\_\_\_

Station/Location      1      2      3      4      5      6      7      8      9      10


Faulting      —      —      —      —      —      —      —      —      —      —  
Remarks

Station/Location      1      2      3      4      5      6      7      8      9      10


Faulting      —      —      —      —      —      —      —      —      —      —  
Remarks

Station/Location      1      2      3      4      5      6      7      8      9      10


Faulting      —      —      —      —      —      —      —      —      —      —  
Remarks

\*See Highway Pavement Distress Identification Manual

### Exhibit 6.4-V PORTLAND CEMENT CONCRETE PAVEMENT CONDITION SURVEY\*

### Portland Cement Concrete Pavement Condition Survey (cont) Instructions

#### Distress Information

- a. Amount of faulting - greater than or equal to 3 mm (0.1 in), 1 m (3 ft) from curb joint.
- b. Location and severity of all cracks located from joint -
  - L = hairline (less than 2 m (6.5 ft) long - do not survey)
  - M = working crack - less 13 mm (0.5 in) fault
  - H = greater than 25 mm (1 ft) and/or greater than 13 mm (0.5 in)

#### Maintenance and Repair

- a. Edge drain installations - location of cut areas  
|CUT→                      ←CUT|
- b. Joint repair due to spalls
  - L = less than 75 mm (3 in) from joint
  - M = 75 mm (3 in) to 150 mm (6 in) from joint
  - H = greater than 150 mm (6 in) from joint

- c. Asphalt patch area and location
- d. Mudjacking hole locations

#### General Information

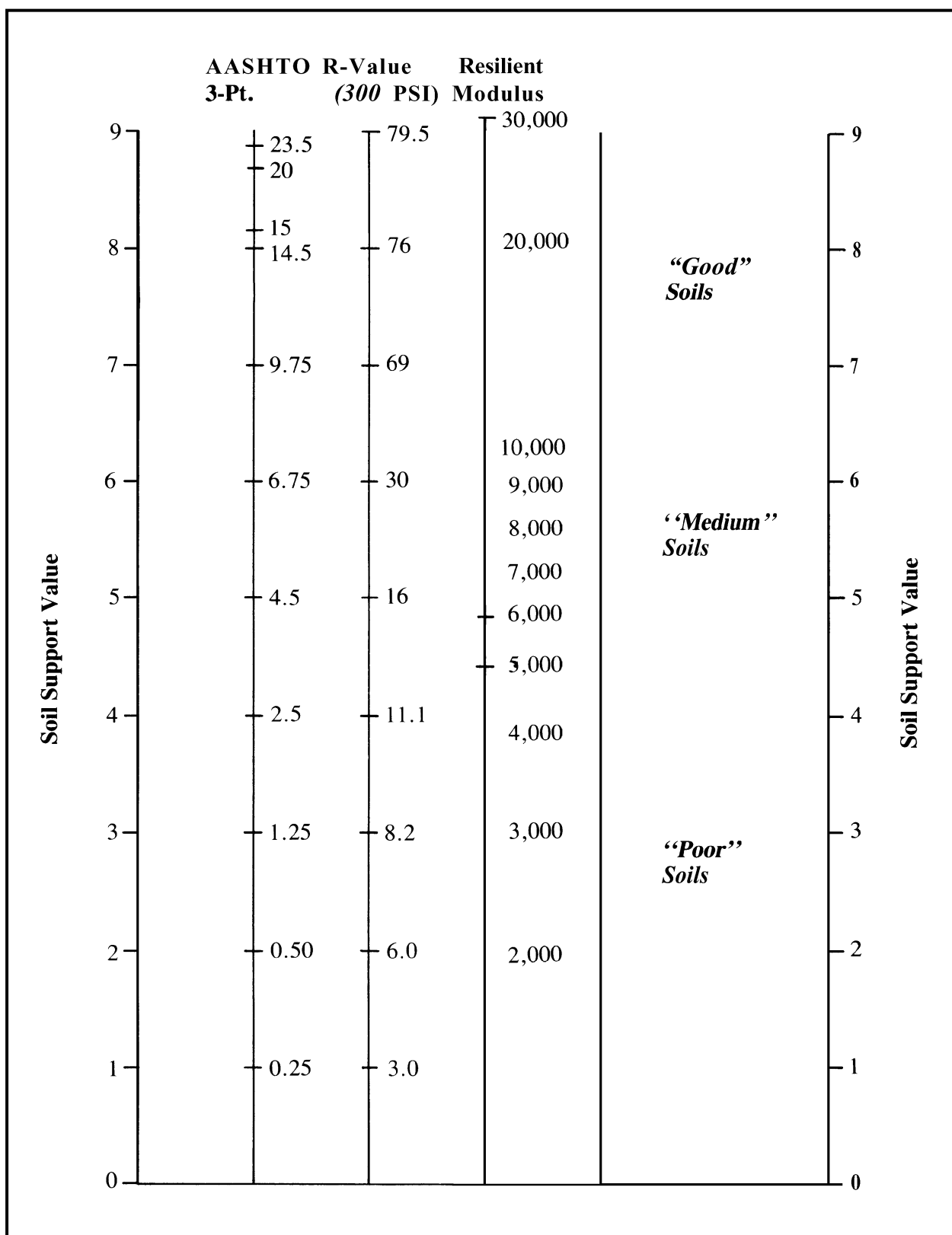
- a. Station number locations
- b. Marking beginning and ending locations of entrance and exit ramps
- c. Location of mainline and overhead bridges, culverts and inlets
- d. Location of expansion joints - traverse (slab length)
- e. Joint spacing - longitudinal (slab width)
- f. Record road grade as uphill (+) or downhill (-)
- g. Joint width (nearest 3 mm (0.1 in)) - put in remarks section of survey form
- h. Slab dip (↓ → down from profile)
- i. Faulting measurement for each joint is to be recorded in the space provided under each joint
- j. Notations such as grade, super elevation, grinding and such other information which remain constant for considerable distances need only be noted on the first and last slab on each survey sheet and at its beginning and ending occurrence. The arrow must be included to indicate that the condition is occurring on all slabs and not in the individual slab marked.

### Exhibit 6.4-V PORTLAND CEMENT CONCRETE PAVEMENT CONDITION SURVEY\* (Continued)

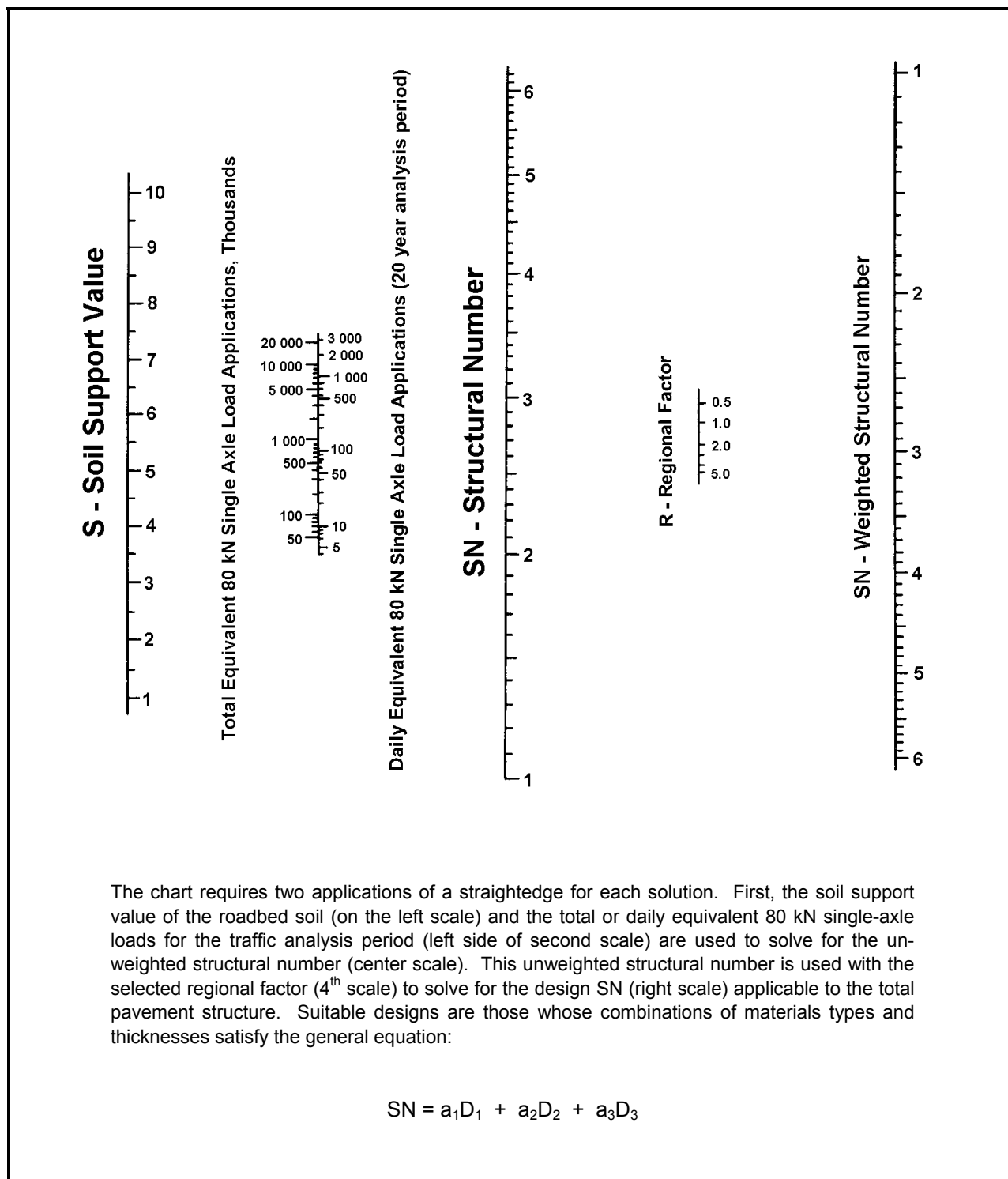


*To Be Provided*

**Exhibit 6.4-W SOIL SUPPORT CORRELATIONS  
(Metric)**



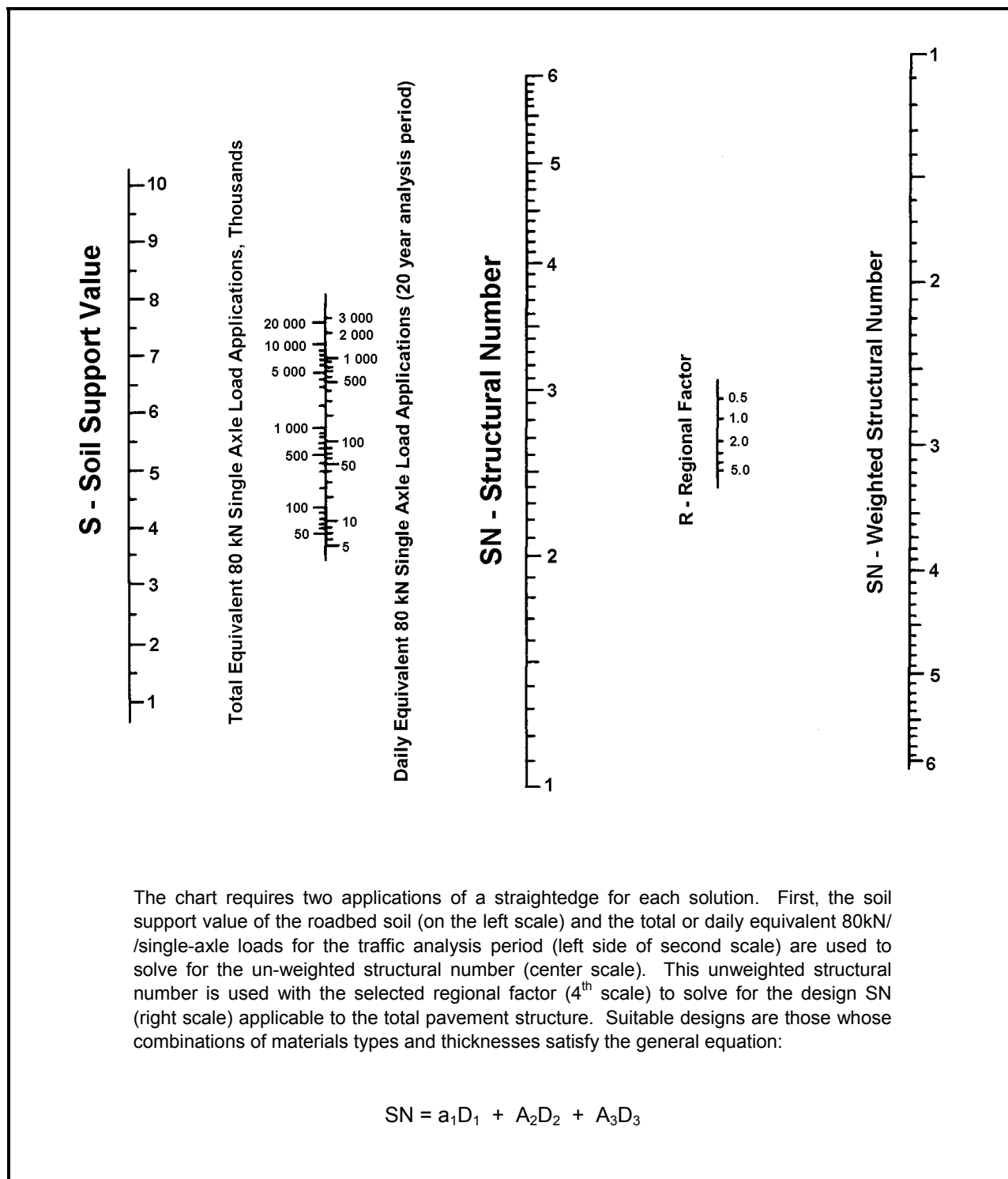
**Exhibit 6.4-W SOIL SUPPORT CORRELATIONS  
(US Customary)**



**Exhibit 6.4-X DESIGN CHART FOR FLEXIBLE –  $P_t = 2.0$   
(Metric)**

*To Be Provided*

**Exhibit 6.4-X DESIGN CHART FOR FLEXIBLE –  $P_t = 2.0$   
(US Customary)**



**Exhibit 6.4-Y DESIGN CHART FOR FLEXIBLE PAVEMENTS –  $P_t = 2.5$   
(Metric)**

*To Be Provided*

**Exhibit 6.4-Y DESIGN CHART FOR FLEXIBLE PAVEMENTS –  $P_t = 2.5$   
(US Customary)**

<b>Pavement Structure Layer Thickness Worksheet</b>																										
Project _____ Section _____ From: _____					Prepared By: _____ To: _____ Date: _____																					
<p style="text-align: center;"><b>Traffic Analysis</b></p> <p>             AADT   X   DY   X   365X   DDF   X   LDF   X   LF   =   Total 80kN ESAL Design              _____ X _____ X 365X _____ X _____ X _____ = _____ Use <span style="border: 1px solid black; padding: 2px 20px;"> </span> </p> <p>             AADT = (Present ADT + Future ADT)/2 Load Factor (LF) = 80kN Equivalent Load Factor per              DY   = Number of Design Years (Typ. 20)                      Vehicle              DDF   = Directional Factor (Typ. .5)              LDF   = Lane Distribution Factor (Typ. 1.0)           </p>																										
<p style="text-align: center;"><b>Regional Factor (RF)</b></p> <p>Precipitation (mm/yr) _____ Pf _____</p> <p>Average Elev. (m) _____ Ef _____</p> <p>Drainage _____ Df _____</p> <p style="text-align: right;">Total RF <span style="border: 1px solid black; padding: 2px 20px;"> </span></p>					<p style="text-align: center;"><b>Existing Pavement Structure</b></p> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 20%; text-align: center;">Material Type</th> <th style="width: 20%; text-align: center;">Thickness Range</th> <th style="width: 30%; text-align: center;">Strength Range</th> </tr> </thead> <tbody> <tr> <td>Surface</td> <td>_____</td> <td>_____</td> <td>_____</td> </tr> <tr> <td>Base</td> <td>_____</td> <td>_____</td> <td>_____</td> </tr> <tr> <td>Subbase</td> <td>_____</td> <td>_____</td> <td>_____</td> </tr> </tbody> </table>							Material Type	Thickness Range	Strength Range	Surface	_____	_____	_____	Base	_____	_____	_____	Subbase	_____	_____	_____
	Material Type	Thickness Range	Strength Range																							
Surface	_____	_____	_____																							
Base	_____	_____	_____																							
Subbase	_____	_____	_____																							
<p style="text-align: center;"><b>Soil Support Value</b></p> <p> <i>Description:</i> _____ <i>Classification:</i> _____  <i>No. Samples Taken:</i> _____ <i>Range of Test Values</i> _____  <i>Type of Tests:</i> _____ <i>No. of Tests:</i> _____ <i>Design Test Value:</i> _____           </p> <p style="text-align: right;">Design Soil Support Value <span style="border: 1px solid black; padding: 2px 20px;"> </span></p>																										
Design Terminal Serviceability (Pf) = <span style="border: 1px solid black; padding: 2px 20px;"> </span>																										
Required Structural Number (SN) = <span style="border: 1px solid black; padding: 2px 20px;"> </span>																										
<b>Pavement Structure Alternatives</b>																										
Pavement Component	Typical Range of Structural Coefficient (SC)	Alternative #1 Design			Alternative #2 Design			Alternative #3 Design																		
		SC	Thick.	SN	SC	Thick.	SN	SC	Thick.	SN																
	$\times 10^{-3}$																									
Seal Coat	0 – 1.97																									
Plant Mix Seal	9.84 – 19.68																									
Plant Mix Surfacing	13.78 – 17.72																									
Road Mix Surfacing	7.87 – 9.84																									
Stab. Base Plant Mix	9.84 – 11.81																									
Stab. Base Road Mix	5.91 – 7.87																									
Stab. Base Emulsion	4.72 – 11.02																									
Stab. Base Cement	4.72 – 9.45																									
Stab. Base Lime	4.72 – 9.45																									
Crushed Agg. Base	3.94 – 5.91																									
Gravel Base	2.75 – 5.51																									
Select Borrow	1.97 – 3.94																									
Exist Roadway																										
<b>Totals</b>																										

**Exhibit 6.4-Z PAVEMENT STRUCTURE LAYER THICKNESS WORKSHEET**  
(Metric)

Pavement Structure Layer Thickness Worksheet										
Project <u>OR FN 141</u>					Prepared By: <u>M. Symons</u>					
Section <u>1</u>					From: <u>MP 125</u>		To: <u>MP 130</u>		Date: <u>1-27-95</u>	
Traffic Analysis										
AADT	X	DY	X	365X	DDF	X	LDF	X	LF	= Total 80kN ESAL Design
<u>200</u>	X	<u>20</u>	X	<u>365X</u>	<u>.5</u>	X	<u>1</u>	X	<u>.8</u>	= <u>584,000</u> Use <span style="border: 1px solid black; padding: 2px;"><u>600,000</u></span>
AADT = (Present ADT + Future ADT)/2 Load Factor (LF) = 80kN Equivalent Load Factor per DY = Number of Design Years (Typ. 20)      Vehicle DDF = Directional Factor (Typ. .5) LDF = Lane Distribution Factor (Typ. 1.0)										
Regional Factor (RF)					Existing Pavement Structure					
Precipitation (mm/yr) <u>500</u> P <sub>f</sub> <u>1.0</u>					Material      Thickness      Strength					
Average Elev. (m) <u>2400</u> E <sub>f</sub> <u>0.5</u>					Type      Range      Range					
Drainage <u>Poor</u> D <sub>f</sub> <u>1.0</u>					Surface <u>BST</u> <u>25-50mm</u> <u>None</u>					
					Base <u>Gravel</u> <u>100-200mm</u> <u>None</u>					
					Subbase <u>None</u> <u>-</u> <u>-</u>					
Total RF <span style="border: 1px solid black; padding: 2px;"><u>2.5</u></span>										
Soil Support Value										
Description: <u>Clay Gravel</u>					Classification: <u>A-2-4</u>					
No. Samples Taken: <u>8</u>					Range of Test Values <u>30-50</u>					
Type of Tests: <u>R-Value</u>					No. of Tests: <u>6</u> Design Test Value: <u>35</u>					
Design Soil Support Value <span style="border: 1px solid black; padding: 2px;"><u>6.2</u></span>										
Design Terminal Serviceability (P <sub>f</sub> ) = <span style="border: 1px solid black; padding: 2px;"><u>2.5</u></span>										
Required Structural Number (SN) = <span style="border: 1px solid black; padding: 2px;"><u>2.80</u></span>										
Pavement Structure Alternatives										
Pavement Component	Typical Range of Structural Coefficient (SC)	Alternative #1 Design			Alternative #2 Design			Alternative #3 Design		
		SC	Thick.	SN	SC	Thick.	SN	SC	Thick.	SN
	$\times 10^{-3}$	$\times 10^{-3}$			$\times 10^{-3}$			$\times 10^{-3}$		
Seal Coat	0 – 1.97									
Plant Mix Seal	9.84 – 19.68									
Plant Mix Surfacing	13.78 – 17.72	13.78	80	1.10	13.78	100	1.38	13.78	120	1.65
Road Mix Surfacing	7.87 – 9.84									
Stab. Base Plant Mix	9.84 – 11.81									
Stab. Base Road Mix	5.91 – 7.87							7.87	150	1.18
Stab. Base Emulation	4.72 – 11.02									
Stab. Base Cement	4.72 – 9.45									
Stab. Base Lime	4.72 – 9.45									
Crushed Agg. Base	3.94 – 5.91	5.51	250	1.38	5.51	275	1.51			
Gravel Base	2.75 – 5.51									
Select Borrow	1.97 – 3.94									
Exist Roadway		3.00	100	0.30	0	0	0	0	0	0
Totals			330 (New)	2.78		375	2.89		270	2.84

**Exhibit 6.4-Z PAVEMENT STRUCTURE LAYER THICKNESS WORKSHEET**  
(Continued)



*To Be Provided*

**Exhibit 6.4-Z PAVEMENT STRUCTURE LAYER THICKNESS WORKSHEET  
(US Customary)**

### Material Investigation Checklist

**Project:** \_\_\_\_\_

**Location:** \_\_\_\_\_

**Prepared by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Is material site location (include description of existing or proposed access routes, bridge load limits, etc.) identified?			
2. Have representative samples of materials encountered during the investigation been tested?			
3. Are laboratory quality test results included in the report?			
4. Aggregate sources.			
a. Do the laboratory quality test results (e.g., LA abrasion, sodium sulfate, degradation, absorption, reactive aggregate) indicate acceptable materials can be obtained from the deposit using normal processing methods?			
b. If acceptable material cannot be obtained from the source using normal processing methods, have special requirements been provided for processing or controlling production?			
5. Borrow sources, have possible difficulties (e.g., above optimum moisture content clay-silt soils, waste due to high PI, boulders) been noted?			
6. Where high moisture content clay-silt soils must be used, are recommendations provided on the need for aeration to allow the materials to dry out sufficiently to meet compaction requirements?			
7. Has previous use of proposed source been discussed?			
8. Does estimated quantity of proven material satisfy the estimated project needs?			
9. Where materials will be excavated from below the water table, has seasonal fluctuation of the water table been determined?			

### Exhibit 6.4-AA SAMPLE OF MATERIAL SOURCE INVESTIGATION CHECKLIST

**Material Investigation Checklist (continued)**

	Check Appropriate Box		
	Yes	No	Not Applicable
12. Has a material site sketch (plan and profile) been provided for inclusion in the plans, which contains:			
• Material site number or identification?			
• Owner identified?			
• North arrow and legal subdivision?			
• Test hole or test pit logs, location, number and date?			
• Water table elevation and date?			
• Depths of unsuitable layers including overburden which are not acceptable.			
• Potential disposal areas?			
• Potential mining area and previously mined areas?			
• Existing stockpile locations?			
• Existing or potential access roads?			
• Bridge load limits?			
• Reclamation details?			
13. Are recommended contract provisions provided?			

Comments \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Exhibit 6.4-AA SAMPLE OF MATERIAL SOURCE INVESTIGATION CHECKLIST**  
(Continued)

### Landslide Correction Checklist

**Project:** \_\_\_\_\_

**Location:** \_\_\_\_\_

**Prepared by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Does the report include a site plan and typical cross section showing ground surface conditions both prior to and after failure?			
2. Has a site reconnaissance been conducted to define the limits of the slide improvement?			
3. Are slide limits (including location of ground surface cracks, head scarp and toe bulge) shown on the site plan?			
4. Is past history (movement history, maintenance work and costs and corrective measures taken) of slide are summarized?			
5. Is summary given of results of size investigation, field and lab testing and stability analyses, including cause(s) of the slide?			
6. Is as-built cross section (used for slide stability analysis) included and does cross section show major soil and rock layers and water table location as determined from drilling and sampling?			
7. Is location of slide failure plane (determined from slope indicators and/or drilling) shown on the slide cross section?			
8. Are soil strength values, soil unit weights, and water table elevation(s) (used in the design stability analyses) shown on the slide cross section?			
9. For existing active slide, was soil strength along slide failure plane backfigured using a safety factor equal to 1.0 at time of failure?			
10. Is the following included for each proposed correction alternative:			
a. Cross section of proposed alternative?			
b. Estimated safety factor?			
c. Estimated cost?			
d. Advantages and disadvantages?			

**Exhibit 6.4-BB SAMPLE OF LANDSLIDE CORRECTION CHECKLIST**

### Landslide Correction Checklist

**Project:** \_\_\_\_\_

**Location:** \_\_\_\_\_

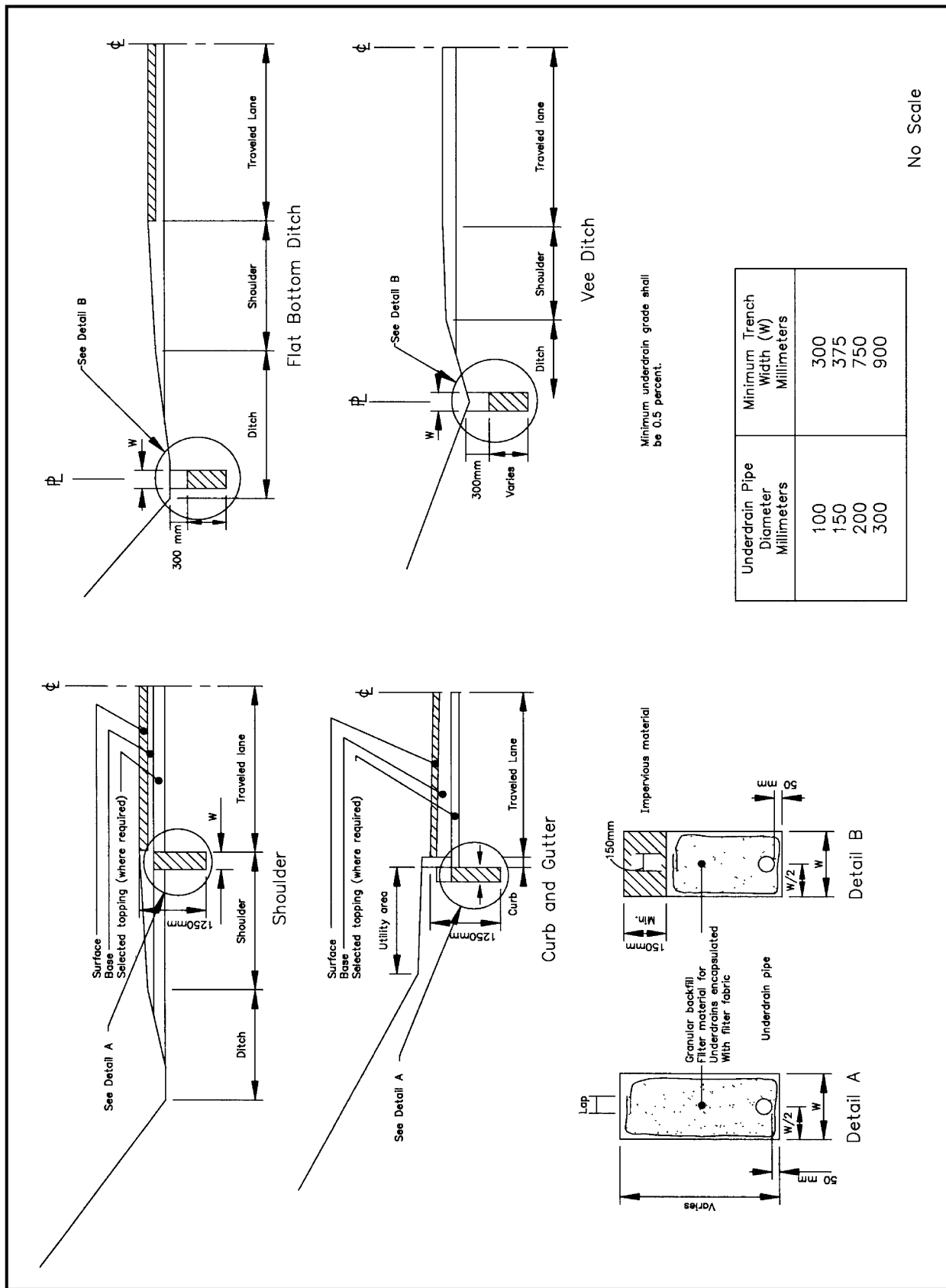
**Prepared by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

Components (continued)	Check Appropriate Box		
	Yes	No	Not Applicable
11. Is recommended correction alternative given?			
12. Does proposed correction alternative provide a minimum FS = 1.25?			
13. Have the most feasible and cost-effective correction alternatives been considered for the particular slide problem? (typical correction methods include buttress, shear key, rebuild slope, surface drainage, subsurface drainage - interceptor drain trenches or horizontal drains - and retaining structures).			
14. If horizontal drains are proposed as part of slide correction, has subsurface investigation located definite water bearing strata that can be tapped with horizontal drains?			
15. If a toe counter berm is proposed to stabilize an active slide, has field investigation confirmed that the toe of the existing slide does not extend beyond the toe of the proposed counter berm?			
16. Construction considerations:			
a. Where proposed correction will require excavation into the toe of an active slide (e.g., for buttress or shear key) has the construction backslope FS been determined?			
b. Has seasonal fluctuation of groundwater table been determined and was highest water level used in computing open excavation backslope FS?			
c. If open excavation FS is near 1.0, has excavation stage construction been proposed?			
d. Should slide repair work only be allowed during driest period or the year?			
e. Should stability of excavation backslope be monitored?			
17. Are recommended contract specifications provided?			

Comments \_\_\_\_\_

\_\_\_\_\_

### Exhibit 6.4-BB SAMPLE OF LANDSLIDE CORRECTION CHECKLIST (Continued)



**Exhibit 6.4-CC TYPICAL UNDERDRAIN INSTALLATION FOR ROADBEDS AND DITCHES (Metric)**

*To Be Provided*

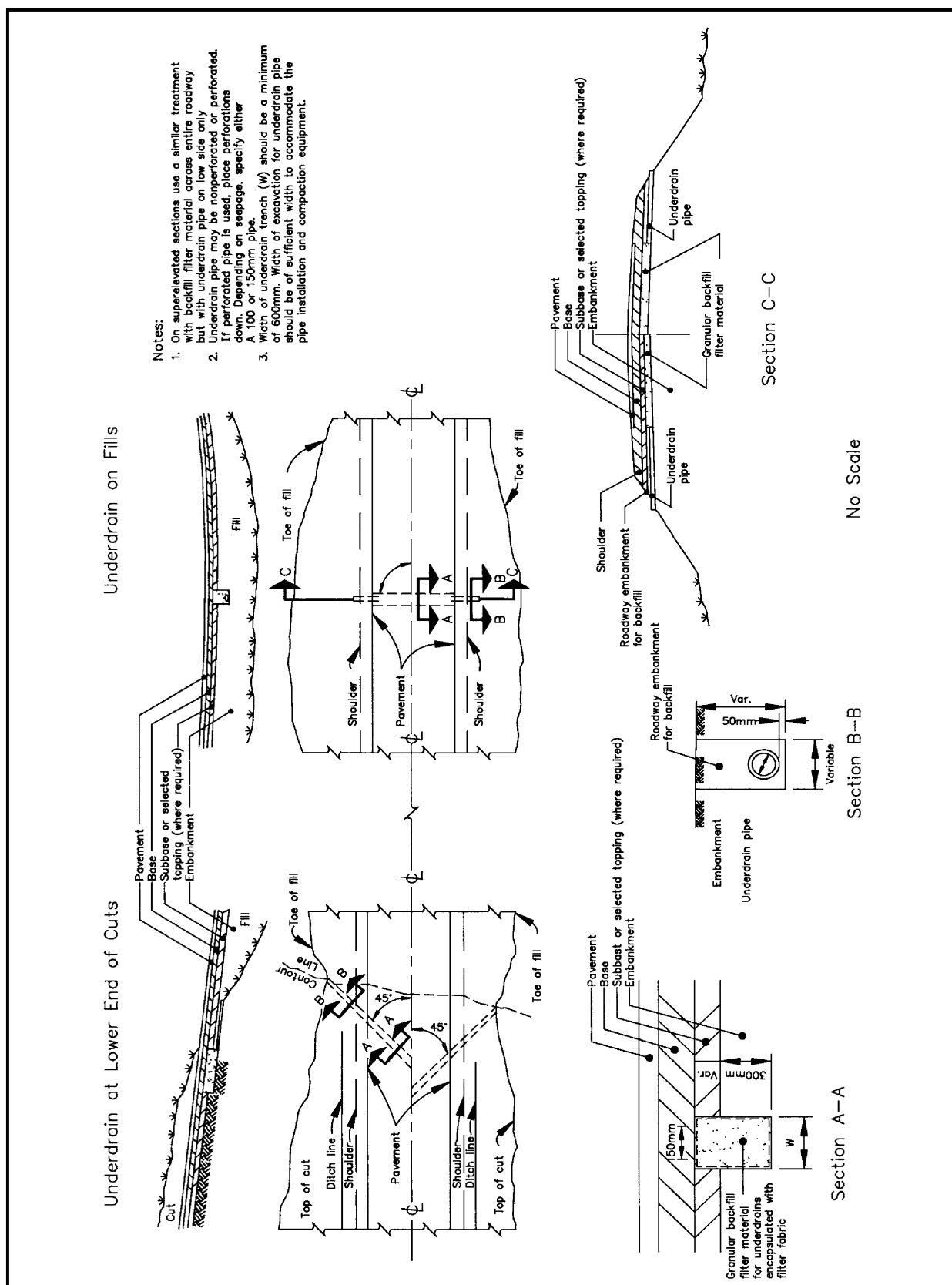
**Exhibit 6.4-CC TYPICAL UNDERDRAIN INSTALLATION FOR ROADBEDS AND DITCHES  
(US Customary)**





*To Be Provided*

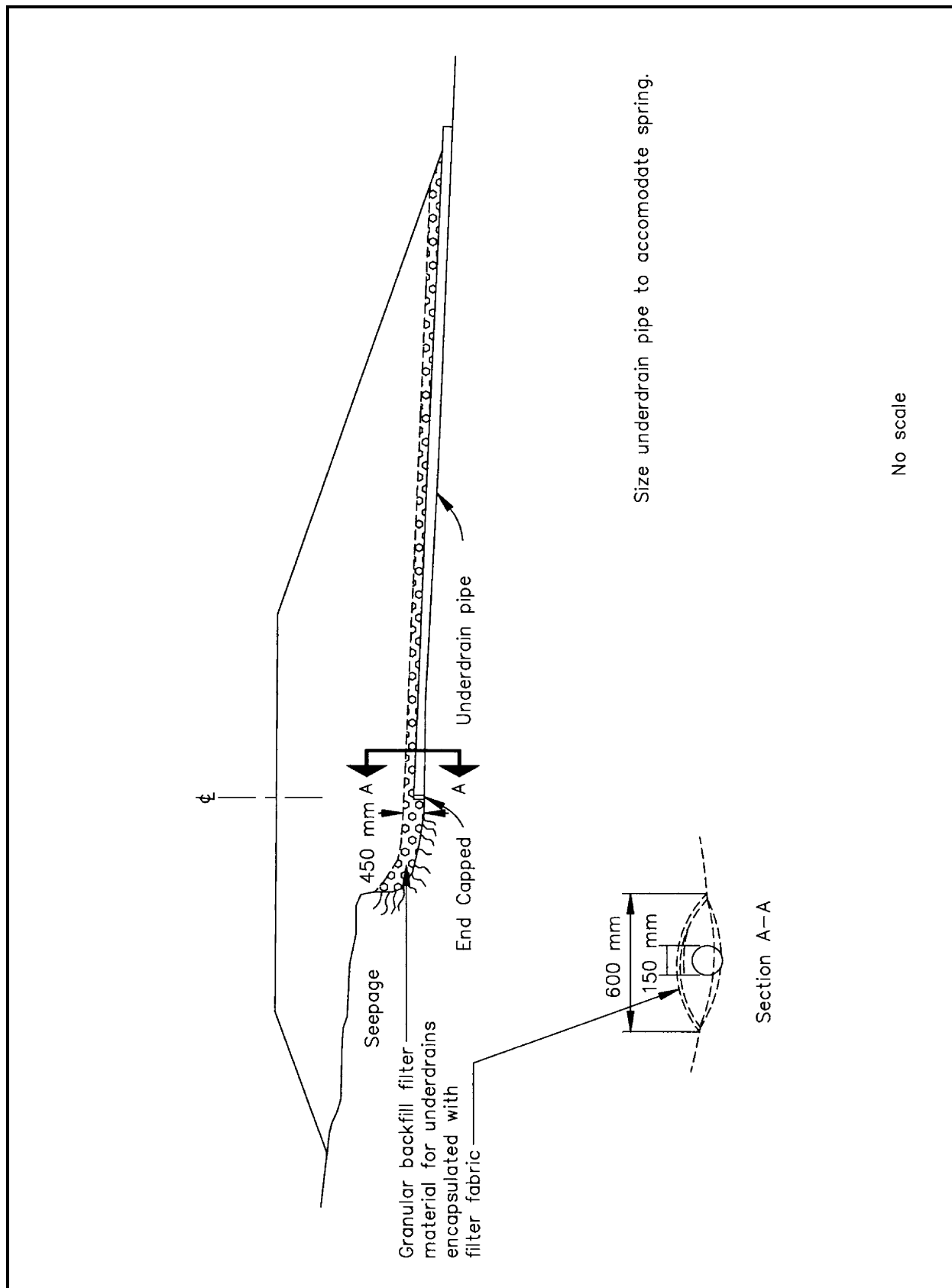
**Exhibit 6.4-DD TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED  
(US Customary)**



**Exhibit 6.4-EE TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED (Metric)**

*To Be Provided*

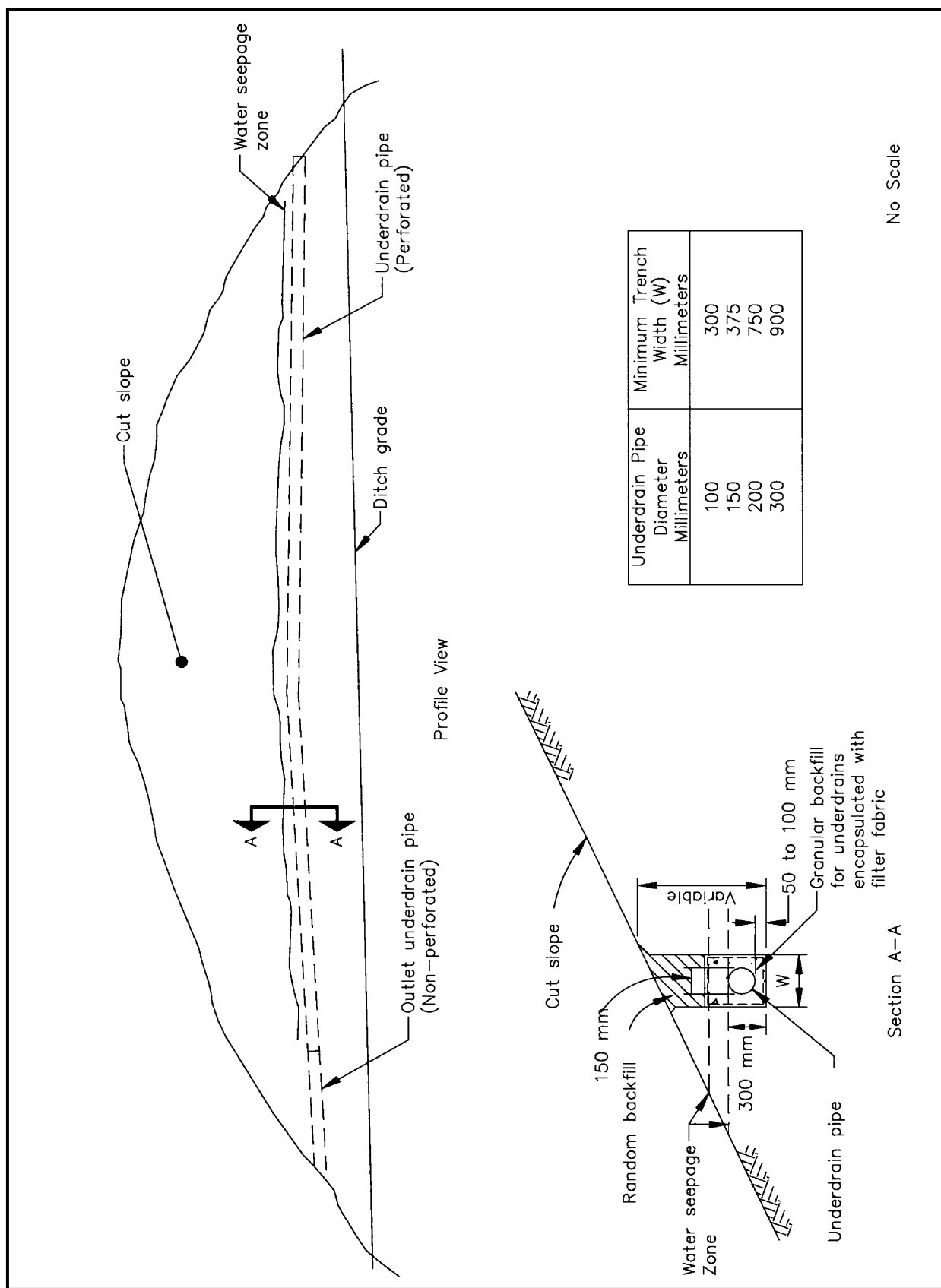
**Exhibit 6.4-EE TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED  
(US Customary)**



**Exhibit 6.4-FF TYPICAL UNDERDRAIN INSTALLATION FOR SPRING AREAS (Metric)**

*To Be Provided*

**Exhibit 6.4-FF TYPICAL UNDERDRAIN INSTALLATION FOR SPRING AREAS  
(US Customary)**



**Exhibit 6.4-GG TYPICAL UNDERDRAIN INSTALLATION FOR BACKSLOPE (Metric)**

*To Be Provided*

**Exhibit 6.4-GG TYPICAL UNDERDRAIN INSTALLATION FOR BACKSLOPE  
(US Customary)**

## **6.5 APPROVALS**

*Reserved*



## 6.6 GEOTECHNICAL REPORTS

The purpose of Geotechnical Reports is to transmit and document all pertinent geotechnical information in a systematic, concise format with specific design recommendations and alternatives. Pertinent information should consist of:

- site specific physical, environmental and geological data (e.g., field boring logs);
- station-by-station field notes;
- geophysical field data;
- material properties laboratory test results;
- discussion of analyses used;
- listing of all major assumptions and/or data used for analyses; and
- design and construction recommendations.

Reports are primarily intended for highway designers, but are also made available to project construction personnel and prospective bidders.

### 6.6.1 REPORT STRUCTURE AND OUTLINE

All geotechnical reports should be consistent and organized to follow the same general structure to allow for familiarity by even the occasional reader. The following topic areas should be considered for final reports:

- introduction,
- procedures and results,
- analysis,
- discussion,
- recommendations, and
- appendices and attachments (as required).

The introduction section of the Geotechnical Report should contain information as to the specific location of the project site, the purpose of the report, authorization for the work and any limitations and restrictions that may apply.

Include a review of the project and history of the site as background information when it is relevant to the investigation and/or proposed project.

The procedures and results reported should contain information as to what field procedures and tests were performed and what engineering values were determined from the test results. Discuss the existing conditions and pertinent geological setting and features in the report. Use data summaries, tables and charts whenever possible. Document any previous report and/or other specific references used to generalize conditions, estimate engineering parameters and develop recommendations. Include all test data, both field and laboratory, in the report and reference in the appropriate appendices.

The analysis section of a Geotechnical Report should contain information as to what type of analyses were performed. When appropriate, include the applicable analysis procedures, including limitations and pertinent assumptions.

The discussion section of the report should draw upon all the previously mentioned sections and present the various possible alternative solutions that were considered for each specific feature or project. Include a general discussion that communicates the major advantages and disadvantages of each alternative.

Recommendations in the report should be concise and directed to the preferred alternative. All detailed information necessary to design and construct the recommended alternative should be provided and all reference literature cited. Identify areas where special treatment may be required and make recommendations on the type of treatment or corrective action to be taken.

The appendices of a Geotechnical Report should contain all detailed laboratory test results, boring logs and field test data used to generate the report. Specific calculations would not normally be included, but all standard terminology and reference charts used to prepare the report are included.

The following is a basic outline guide:

- Title Page;
- Table of Contents;
- Introduction;
- Procedures and Results;
- Analysis;
- Discussion;
- Recommendations;
- Attachments (e.g., Location Map, Drawings);
- Appendix A - Field Bore/Core Log;
- Appendix B - Laboratory Test Results;
- Appendix C - Geophysical Test Results; and
- Appendix D, etc. - Photographs, miscellaneous test results and/or information as deemed necessary.

## **6.6.2 CHECKLISTS**

As a guide to ensure that all pertinent items are considered in Geotechnical Reports, checklists have been prepared from FHWA's 1985 publication [\*Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications\*](#). These checklists are presented as [Exhibits 6.4-I](#), [6.4-A](#), [6.4-N](#), [6.4-O](#), [6.4-P](#), [6.4-Q](#), [6.4-R](#), [6.4-AA](#) and [6.4-BB](#). The checklists are intended to be used primarily by reviewing and approving officials. Therefore, all

geotechnical project engineers and geologists preparing reports should become very familiar with the contents, concepts and procedures presented in the checklists. [Exhibits 6.4-I](#) and [6.4-A](#) contain information that is generally common to all Geotechnical Reports. [Exhibits 6.4-N](#) through [6.4-BB](#) are to be used for specific items addressed in specialized Geotechnical Reports.

### **6.6.3     STANDARD FORMS**

Geotechnical forms that are common to all Federal Lands Highway Divisions have been standardized and are presented in Exhibits in the applicable Sections. Completed examples of the more routinely used forms are also included within these Exhibits.

## **6.7 DIVISION SUPPLEMENTS**

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this Chapter with appropriate Division procedures and direction.

### **6.7.1 EFLHD SUPPLEMENTS**

Refer to the EFLH Division Supplements.

### **6.7.2 CFLHD SUPPLEMENTS**

Refer to the CFLH Division Supplements.

### **6.7.3 WFLHD SUPPLEMENTS**

Refer to the WFLH Division Supplements.